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Studies on Center-line Shrinkage In Steel Castings†

By S. W. Brinson* and J. A. Duma*, Portsmouth, Va.

Abstract

It has been found that the interior metal of steel castings ¼ to 4 in. thick—made of basic steel, molded in sand molds, and solidified under inadequate temperature gradient—is invariably weakened with macroscopic shrinkage voids oriented in the direction of hottest metal and arranged in a definite characteristic pattern. The defective condition is referred to in the pages as center-line shrinkage.

The influence of center-line shrinkage on mechanical properties is manifested in the fluctuation of the elongation and reduction in area values, decreased longitudinal tensile strength, erratic notch sensitivity, and decreased specific gravity. The defect also makes thin castings hydraulically unsound, causing them to leak when subjected to high water, steam, or air pressure.

The report shows how, by proper application of padding, center-line shrinkage can be completely eliminated. The amount of padding required to do this is a function of the height and thickness of the section. For sections 12 in. high the amount of padding required varies inversely as the thickness, namely—from 2.60 in. per ft. on 1-in. thick sections to 0.15 in. per ft. for the 4-in. thick sections. Sections of the same height but thicker than 4½ in. require no padding.

Regarding the influence of height, the amount of padding required in inches per inch increases for specimens up to 12 in. high, the increase being of a lower order for the heavier sections. And conversely, the amount of padding in inches per inch needed for specimens higher or longer than 12 in. decreases with height, the decrease being of a higher order for the thinner sections. Approximately one half as much padding in inches per inch is

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* Master molder and associate metallurgist respectively, Norfolk Navy Yard.

Note: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

required for specimens 24 in. high as for the same specimens 12 in. high.

It is also shown that the many secondary factors which are generally inclined to influence the character of feeding,—such as casting temperature, mode of crystallization, capillarity, gas evolution, metal pressure, rate of solidification, molding sands, risering, casting position, and composition of the metal—exert comparatively minor, and in some instances, negligible effects on center-line shrinkage.

FOREWORD

1. A previous paper entitled "The Application of Controlled Directional Solidification to Large Steel Castings" was presented by the authors at the 1940 annual meeting of this association. This paper described the use of applying padding or wedging the casting to overcome center line shrinkage or as it has otherwise been called "midwall shrinkage."

2. Since presenting this paper the authors have been asked the question many times if there were any figures as to the correct amount of padding or wedging that should be applied. Our only answer to date has been that the Navy Department had authorized tests to be made at the Norfolk Navy Yard to try to determine the quantitative answer. A few steel foundrymen and others interested in steel casting problems, who have visited our plant, after we had completed some of the tests, were shown the results as a matter of interest.

3. The Navy Department, being one of the largest customers in the country for important steel castings, has authorized this test and a report on the findings at this meeting with the belief that this report would help steel foundrymen to better meet its rigid requirements and specifications; and that it will enable them to furnish better steel castings, which are so essential in all defense work.

4. When the test had been authorized, the question naturally arose as to the best method of attacking the problem. The authors who have been the ones principally involved in developing and carrying the test through to the conclusion, decided on a plate 12 in. high, 10 in. wide and 1 in. thick as the representative of basis; the average of steel castings made at the Norfolk Navy Yard. With this standard plate as a basis the first step was to cast several of these plates varying from a constant section to 4 in. of wedging. A plate with a specially designed curve wedge was also tried with

the idea of saving metal. We had previously heard a statement made by a steel foundryman that center-line or midwall shrinkage would occur in sections cast vertically but not when cast horizontally, so we then went to a horizontal position in casting the plates and then integrated by casting them at an angle of 45 degrees.

5. These tests were made under different mold and casting conditions. The size of riser first adopted proved insufficient for some of the heaviest wedged castings, so the size of the riser was changed. All castings for the regular tests were gated at the joint in order to get the hottest metal in the riser, this being the most favorable condition. Tests were cast in both green and dry sands and also in a combination of the two to see if the shrinkage would be displaced from the center. In view of the fact that someone advanced a theory that the hotter the metal when poured, the lesser would be the midwall shrinkage, tests were poured at different temperatures, and fluidity spirals as developed at the Naval Research Laboratory were obtained.

6. After making the plain plates in the positions referred to, we further integrated by making some in all positions joined together in one casting, then as a hexagonal section and finally as a circular section. These were made both with and without wedging. Several plates were then made 18, 24 and 28 in. high to ascertain if a greater depth of the casting would change its center-line or midwall shrinkage characteristics. Toward the end of the test we cast several plates ½ in. and ¼ in. in thickness in both green and dry sand to ascertain if the more rapid solidification of the metal would eliminate or otherwise affect midwall shrinkage.

7. With this preliminary history and description of the tests we expect that foundrymen are now much interested in the results obtained. These results we, at least, think are a little on the startling side, showing as they do, what is to us clearly necessary to obtain important castings which are free of center-line shrinkage and which will give clear pictures on radiographic examination.

Statement of the Problem

8. The problem is most simply stated as a study of the phenomenon of center-line shrinkage, the problem's primary concern being the evolvement of fundamental principles wherewith quantitative calculations can be made of the amount of metal padding

needed for the complete elimination of center-line shrinkage from cast steel sections of varying thickness, varying height, and varying position in the mold.

9. In more detail, the investigation resolves itself into the following elementary component tests:

Primary Objects

Test 1: To determine the degree of solidity obtainable in straight, unpadded, elementary sections of varying thickness; *i.e.*, ¼, ½, 1, 2, 3, and 4 in. thick, all 12 in. high and vertically cast.

Test 2: To evaluate the effect of height on the depth and extent of axial shrinkage in vertically cast, unpadded sections, all 1 in. thick but of varying height; *i.e.*, 4, 8, 12, 20, 24, and 28 in. high.

Test 3: To determine the influence of position or angular repose in the mold of uniformly thick, unpadded sections on the extent and displacement of center-line shrinkage in castings 1 in. thick.

Test 4: To find the amount of padding in inches per linear inch of section required to secure axial compactness in vertically cast members, 1 in. thick and 12 in. high.

Test 5: To check the efficacy of tests done in Test 4 on 1-inch sections molded in the flat and 45 degree positions so as to discover the effect of section position on center-line shrinkage in padded designs.

Test 6: To determine the influence of wall thickness and section height on the solidity of axial metal. Specifically, to find the amount of padding needed on sections ½, 1, 2, 3, and 4 in. thick, and 4, 8, 12, 16, 20, 24, and 28 in. high.

Test 7: To discover the most effective side (top or bottom) to pad flat-lying and inclined sections.

Test 8: To discover the effect of metal fluidity (*i.e.*, metal temperature) on the formation of center-line shrinkage.

Test 9: To test sections containing center-line shrinkage for resistance to hydraulic pressure, and determine the effect of this shrinkage on the physical properties of the metal.

Secondary Objects

Test 10: To determine the relative feeding efficiency of a specially designed wedge for overcoming center-line shrinkage and the relative saving in weight effected over that of the regular wedge.

Test 11: To compare the degree of X-ray soundness obtainable in unpadded 1-in. thick sections fed from an open riser with those fed from a blind riser pierced and fitted with an air-permeable, firecracker core.

Test 12: To determine the influence of directional freezing on the center-line of a 1-in. thick plate vertically chill-cast against cambered cast iron wedges.

Test 13: To study the effect on center-line of mold preheat by casting a vertical plate, 1 in. thick, against heated metal mold walls (steel, 1 in. thick, by 10 in. wide, by 12 in. high), one on either side, and preheated to 650°F.
Test 14: To determine the influence of differential chilling such as results from having two thermally different mold materials, one on either side of the casting, on the displacement of the hot metal line (green sand on one side and baked core sand on the other).
Test 15: To discover if other metals, pure and alloyed (electrolytic ingot copper; primary, Grade A aluminum ingot; manganese bronze ingot), are subject to center-lining.

KNOWN FACTS CONCERNING THE PROBLEM

10. The terms, "padding" and "center-line shrinkage", are not new either to foundry technologist or foundry practitioner. Their meaning and full import have been competently interpreted in recent foundry literature*[1, 2]. It is hoped that the following short review of their definition will not be construed as mere retraveling of well-beaten paths.

Padding

11. Padding is a tapered disposition of metal on the walls of castings, the taper increasing in the direction of feed heads. When correctly applied to thin steel members (¼ to 4 in. thick), it is productive of uniformly dense and internally sound cross sections. The increasing volume of metal in the taper of wedged sections, together with the decreased surface area, cause solidification to proceed progressively through them, beginning at the far, narrow extremity and ending at the tapered opposite end. Discounting such mechanical pressure methods of feeding as jolting and centrifugal rotation, which are inapplicable to still foundry molding, progressive solidification alone can insure continuous pressure feeding of hot liquid steel into the filamentary crevices of nascent shrinkage areas which are wont to form in solidifying metal. Progressive solidification leaves the metal solidly compacted, its interior structure freed completely from all microshrinkage such as is known to occur in thin, unpadded sections, wherein fully effective feeding is seldom realized due to the nullification of pressure action by the obstructing branches of bridging dendrites during the final stages of solidification. Padding, in short, is a special method for inducing progressive solidification.

* Superior numbers refer to the bibliography appended to paper.

Center Line Shrinkage

12. Center-line shrinkage, midwall shrinkage, center-line weakness, hot metal line, center-line,—all one and the same phenomenon—is a porous condition of metal consisting of a labyrinth of line cavities whose geometric character changes with viewing position. In vertically cast specimens viewed edgewise, center-line weakness consists of a series of nested, concave-sided macro voids whose vertices possess two unique characteristics: directionalism, and fixity of position. More explicitly, they always point away from, and not to, the feed heads; and, in vertically cast sections, they all lie in a central plane situated between the outer and inner cast surfaces. Center-line shrinkage is a direct consecution of the liquid-to-solid metal contraction naturally inherent to solidifying metal systems. If the direction of this solidification is controlled, center-line shrinkage can be prevented from forming. It will be remembered that it is uniform solidification across a member that generally induces center-line formation, whereas progressive solidification up the member suppresses its formation.

13. Further inquiry into the architecture of center-line discovered the following facts:

(a) *Macrostructure:* Plate 1 pictures the cross sections of three specimens macro-etched with 20 per cent ammonium persulphate solution. Selective attack of a reagent on steel, as is apparent in the photograph, is *prima facie* evidence of physical and chemical heterogeneity. Close inspection of the topography of the etched surfaces will discover two kinds of unsoundness responsible for the weakness of center metal: first, physical discontinuities in the form of vee markings locked in a matrix of "cokey" metal; and

Table 1

CHEMICAL COMPOSITION OF SOLID AND SHRINKAGE METAL

Specimen* Number	Character of Metal	Per Cent C.	Mn.	P.	S.	Si.	Ni.
1	Sound bottom metal	0.24	0.54	0.02	0.02	0.36	0.37
	Center-line metal	0.27	0.56	0.02	0.02	0.36	0.38
2	Sound bottom metal	0.26	0.53	0.02	0.03	0.38	0.34
	Center-line metal	0.31	0.52	0.02	0.02	0.38	0.33
3	Sound bottom metal	0.25	0.54	0.03	0.02	0.41	—
	Sound top center	0.24	0.54	0.02	0.01	0.04	—

* Specimen 1 taken from 1 in. thick casting; specimen 2 from 2 in.; and specimen 3 from 3 in. thick castings.

secondly, chemical segregation in the form of small but nevertheless unequal concentration of elements over the cross section. In Table 1 are given chemical analyses of three different specimens, each analyzed at two different locations. Note that the areas containing center-line shrinkage are consistently higher in carbon. The data are insufficient, however, to permit of formulating accurate generalizations regarding the chemical inhomogeneity of center-line metal.

(b) *Microstructure:* Inspection of the architecture of center-

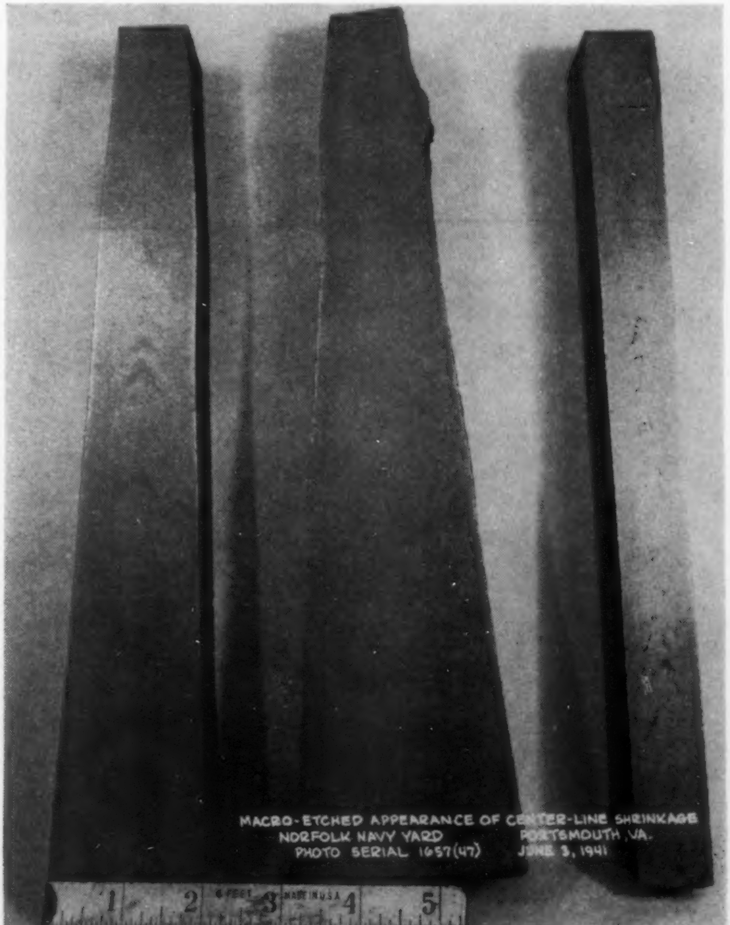


PLATE 1—MACRO-ETCHED APPEARANCE OF CENTER LINE SHRINKAGE.

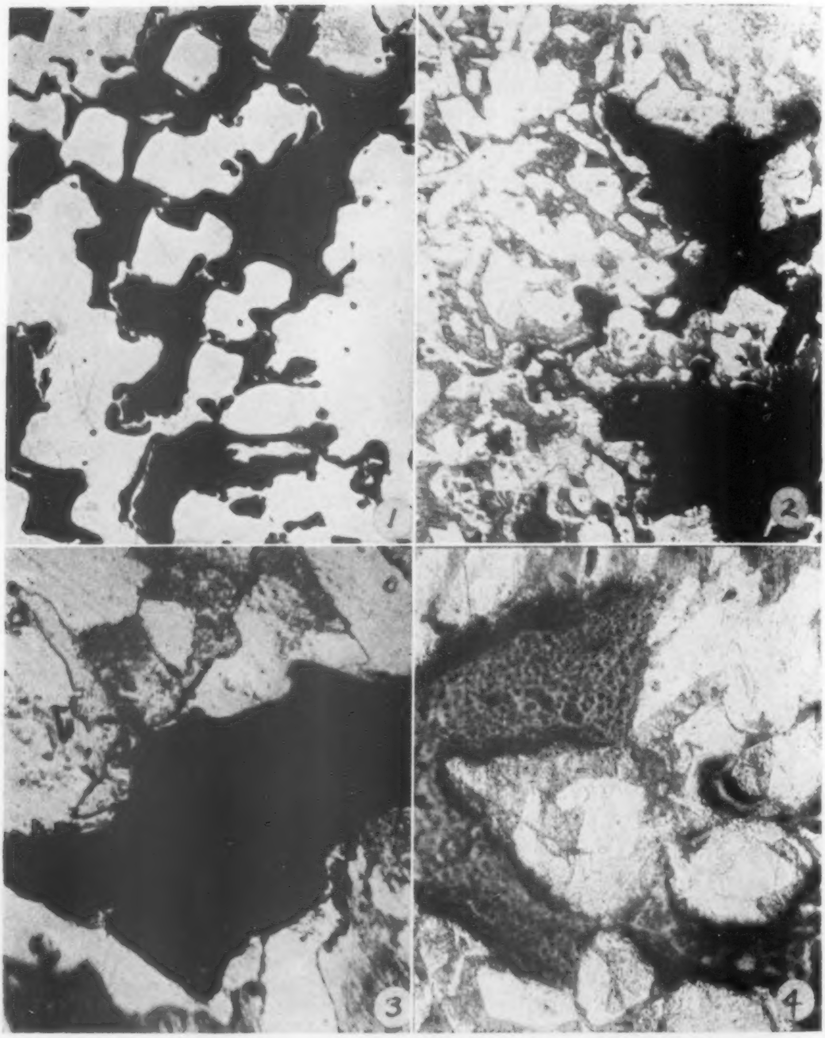


PLATE 2—MICROSCOPIC APPEARANCE OF CENTER-LINE SHRINKAGE—FIG. 1, CENTER-LINE SHRINKAGE IN 1-IN. THICK CAST STEEL SECTION—UNETCHED x100—FIG. 2, STRUCTURE OF STEEL IN VICINITY OF SHRINKAGE AREA—ETCHED IN 3 PER CENT NITAL. x100—FIG. 3, SAME AS FIG. 2. DETAIL OF STRUCTURE ON EDGE OF SHRINKAGE CAVITY—x500—FIG. 4, SAME AS FIG. 2. CAVITY CONTAINING SLAG—x500.

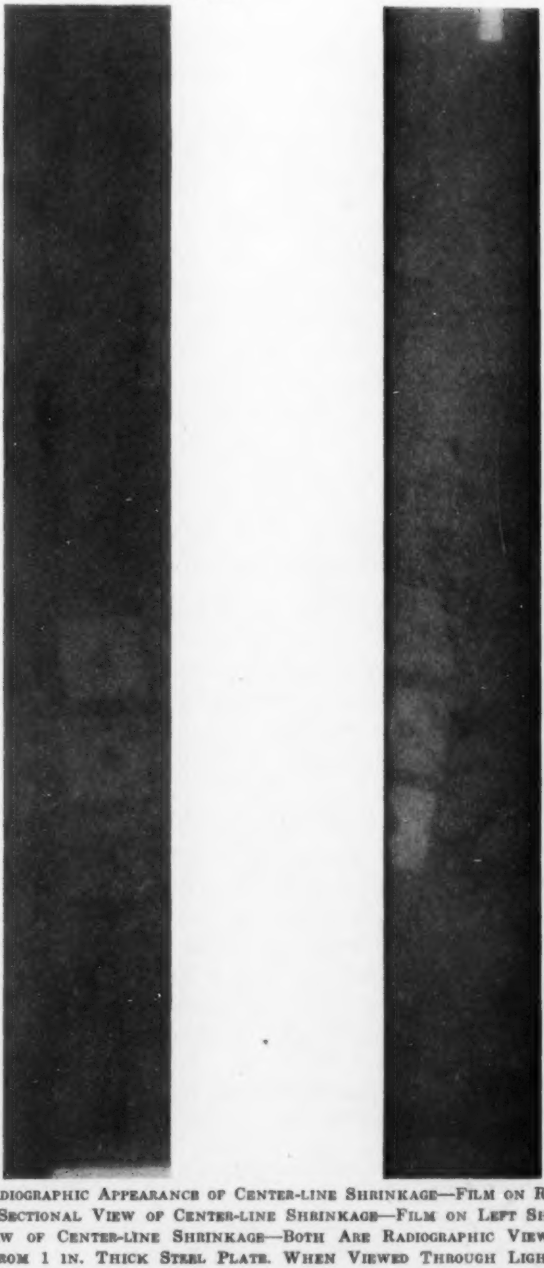


PLATE 3—RADIOGRAPHIC APPEARANCE OF CENTER-LINE SHRINKAGE—FILM ON RIGHT SHOWS SIDE, CROSS SECTIONAL VIEW OF CENTER-LINE SHRINKAGE—FILM ON LEFT SHOWS FRONT, NORMAL VIEW OF CENTER-LINE SHRINKAGE—BOTH ARE RADIOGRAPHIC VIEWS OF ½-IN. SLICE CUT FROM 1 IN. THICK STEEL PLATE. WHEN VIEWED THROUGH LIGHTED GROUND GLASS THE CHARACTERISTIC STRUCTURE OF CENTER-LINE SHRINKAGE MAY BE CLEARLY SEEN—(LEFT) SIDE, CROSS SECTIONAL VIEW OF CENTER-LINE SHRINKAGE. (RIGHT) FRONT, NORMAL VIEW OF CENTER-LINE SHRINKAGE.

line shrinkage under high magnifications (100 to 500 dia., Figs. 1 to 4, inclusive, Plate 2) finds it to be essentially a network of voids lined with tiny beads of metal and projecting microscopic dendrites. Occasionally remnants of slag are found entangled in the cavities. No evidence of gas pressure or its effects were found in the cavities examined.

(c) *Radiographic Structure:* Plate 3 is a three-dimensional shadow picture of the voids constituting center-line shrinkage. Two views, front and side, are shown. Attention is directed to the chevronwise configuration of shrinkage lines in the one; and the vein like pattern of vertical veinlets in the other.

(d) *Inspection For:* Center-line shrinkage is not always visible to the naked eye. Mild and faint cases will escape detection unless special searching methods such as finish-grinding combined with light macroetching, or finish-grinding and X-raying are employed to make it apparent.

GENERAL OBSERVATIONS

14. The practice of padding castings for solidity has been put to intensive use not only by the Yard during the past several years but of late by other reputable steel foundries. Ever since the advent in the steel foundry of gamma-ray inspection, some 10 years ago, and of late the more sensitive X-raying of castings, the use of padding is not only continually widening but is well-nigh compelling.

15. The line of central shrinkage drain evident in radiographs of thin, unpadded sections may be of a type which is not detrimental in most practical applications. But castings intended for steam service and items affecting the safety or military effectiveness of war machinery, are required by radiographic acceptance criteria to be as completely solid as modern foundry technology can make them. Of the methods available to foundrymen for procuring this vital degree of solidity, namely:

(1) Total reversal.
(2) Banking or partial reversal, 20-45°.
(3) Top-pouring of risers.
(4) Heading.
(5) Gating—parting, multiple, and step-wise.
(6) Chilling, coring, design.
(7) Mold materials of varying cooling capacity.
(8) Padding—outside, inside, eccentric.
(9) Sectioning or partitioning of castings.
(10) Preheating the cope.

Padding is the most flexible and adaptable to all manner and size of castings, insuring at all times—of itself and unaided—undisturbed progressive solidification. It is amenable to simple calculation, and is removable by comparatively inexpensive, simple and fairly fast methods (machining, chipping, flame gouging).

16. To the best of our knowledge, those who use padding do so empirically. As with our foundry, so no doubt with others, the amount of padding generally applied is at first determined by trial and error, later by judgment tempered with experience. The latter is not at all times infallible, for what often has proven adequate taper in one instance has proven wholly inadequate taper in many others. Unless all the variables governing the use of padding are evaluated quantitatively, either too much or too little taper will usually be allowed. To answer how much padding is needed to produce castings of high specific gravity throughout (7.83) and of high X-ray density (free from voids down to 0.005 in. in size) is, as already stated, the primary aim of this study.

METHODS AND MATERIALS

17. *Steel:* Center-line shrinkage studies were made on Class B steel, Navy Department Specification 49S1. The steel was made in a 3-ton, basic-lined, Lectromelt arc furnace, using the Yard's regular standard two-slag practice as described elsewhere[3]. Sev-

Table 2

REPRESENTATIVE ANALYSES OF STEEL USED IN THE TESTS

Heat No.	Per Cent *C.*	*Mn.*	*P.*	*S.*	*Si.*	*Ni.*	*Cr.*
B-0-376	.22	.53	.03	.02	.40	.27	.04
B-1-13	.24	.57	.01	.02	.39	.21	.06
B-1-520	.20	.58	.03	.02	.37	.27	.05
B-1-730	.20	.61	.03	.03	.31	.42	.19

Cu.	*Ti.*	*Pouring[1] Temp. °F.*	*Spiral[2] Length in.*	*FeO in Final Slag per cent*
.11	.01	2860	22	0.4
.10	.02	2920	29	0.5
.08	.01	2950	36	0.6
.14	.03	2840	20	0.2

1 Leeds & Northrup Optical Pyrometer.
2 Test described in Naval Research Laboratory Report No. M-1731, 2 May, 1941. See Plate 31 for picture of mold.

eral heats were used to make the various castings, only part of the metal going into experimental wedges, the greater remainder going into miscellaneous ship castings. The chemistry of a few representative heats is shown in Table 2.

18. *Other Metals:* In making castings for Test 15, the following non-ferrous metals were used, each melted in new, pit-fired, No. 90 graphite crucibles:

Metal	*Flux*	*Deoxidizer Phos.-Copper oz. per 100 lb.*	*Pouring Temperature °F.*
Electrolytic Copper	None	1	2050°
Primary Aluminum	None	None	1225°
Manganese Bronze	None	None	1850°
Silicon Monel	*	—	2775°
Gun Metal	Charcoal	1	2060°
Copper-Silicon	Glass	1	2000°

19. *Molding:* Steel specimens were molded in skin-dried, green sand molds; non-ferrous specimens, in green, Grade 00, Albany sand. Unless specifically stated otherwise, all metal was introduced into the mold by way of an L-shaped sprue-gate channel, approximately 2 in. in diameter, connected lipwise over the top width of one of the side edges. (See plates 17 to 22, inclusive.) In Test 14, a facing of green sand, 1½ in. thick, was rammed against one face of the pattern and a baked core was set against the other face, the whole backed up with foundry heap sand. The composition and physical properties of each respective sand are included in Table 3.

20. Regarding the risering of the specimens, all risers were regular truncated polyhedrons (Plates 17-22, inclusive), poured 6 in. high, and blanketed with a ¾ in. thick covering of pipe eliminator immediately after filling of the mold. Since the cube of the minimum cross-sectional dimension of a riser governs the time of its solidification[4], an effort was made to keep that dimension at least 1½ times thicker than the casting,—so as to take the riser approximately 3½ times as long to solidify as the casting. In all instances risers were placed directly atop the thick end of the wedge-shaped test piece. Any vitiating effect which might have been produced by variable ferrostatic pressure, or disproportionate temperature gradients, was thus eliminated from all tests. Further

* $CaCO_3$—$CaFl_2$—Charcoal in ratio of 10:10:2.

control over riser construction and riser design variables was obtained by making nearly all of them weigh approximately 80-85 per cent of the weight of the casting proper. Columns (q) and (r) of Table 4 show that the volume to surface area ratio; *i.e.*, V/SA, of every riser is approximately 1½ times that of the V/SA ratio of the casting it served. The 6-in. height, the 80-85 per cent volume, and the 1½ times greater V/SA values for subject risers were determined in preliminary experimental riser tests by sectioning risers of various heights and design.

21. As for pouring, all steel molds were top-poured from a bottom-pour, 10 ton ladle fitted with a 2-inch pouring nozzle; non-

Table 3

PROPERTIES OF MOLDING SANDS

COMPOSITION

Sand	*A.F.A. Grain Fineness No.*	*Mixture Sand*	*Mixture Bentonite*	*Linseed Oil*	*Natural Clay Per Cent*	*Moisture Per Cent*
Cape Henry	51.72	500 lbs.	45 lbs.	——	——	3.2
Albany	202.70	——	——	——	10.2	7.0
New Jersey	60.80	120 qts.	——	2 qts.	——	5.5

PHYSICAL PROPERTIES[1]

	Perm.	*Comp.*	*Shear*	*Tensile*	*Trans. Shear*	*Flexure*	*Sinter Point*
Cape Henry[2]	295.0	37.5	9.2	....	...	...	2120
Albany[3]	14.0	5.0	1.5	....	...	...	2250
New Jersey[4]	170.0	455.0	..	125.0	32.0	26.8	2200

Cape Henry Sieve No. U.S. Std.	*Cape Henry* Per Cent Retained	*Albany* Sieve No. U.S. Std.	*Albany* Per Cent Retained	*New Jersey* Sieve No. U.S. Std.	*New Jersey* Per Cent Retained
6	0.0	6	0.0	6	0.0
12	0.0	12	0.2	12	0.0
20	0.0	20	0.1	20	0.0
30	1.8	30	0.05	30	Trace
40	8.6	40	0.05	40	1.4
50	27.8	50	0.2	50	13.8
70	34.8	70	2.0	70	41.4
100	23.0	100	2.5	100	33.4
140	3.6	140	13.0	140	8.1
200	0.4	200	12.4	200	1.8
270	0.0	270	26.1	270	0.1
Pan	0.0	Pan	33.2	Pan	0.0
Grain Distribution	2:3:3		8:3:0		2:3:2

[1] Tests made according to the Standards and Tentative Standards of AMERICAN FOUNDRYMEN'S ASSOCIATION Committee on Molding Sand Research (1938).
[2] Dried for one hr. at 225°F.
[3] Green.
[4] Dried for one hr. at 450°F.

Table 4

DIMENSIONS OF TEST SPECIMENS (IN INCHES)

		Casting				Riser				
		Thickness				Thickness		Width		
No. (a)	Fig. (b)	Bottom (c)	Top (d)	Height (e)	Width (f)	Bottom (g)	Top (h)	Bottom (j)	Top (k)	Height (i)
				VERTICAL SPECIMENS						
1	1a	1	1	12	10	1¼	2¼	10	10	6
2	1b	1	2	12	10	2¼	3½	7½	8½	6
3	1c	1	3	12	10	3½	4½	7½	8½	6
4	1d	1	4	12	10	4½	5½	7½	8½	6
5	1f	1	4 Sp.	12	10	3½	4½	7½	8½	6
6	1e	1	5	12	10	5½	6½	7½	8½	6
7	1c	1	3	12	10	3½	4½	7½	8½	6
8	3a	2	4	12	10	5½	6½	7½	8½	6
9	3b	3	5	12	10	7½	8½	7½	8½	6
10	2a	¼	¼	12	10	7/16	13/16	10	10	4
11	2b	½	½	12	10	⅞	1⅝	10	10	4
12	1a	1	1	12	10	1¼	2¼	10	10	6
13	2c	2	2	12	10	2½	3½	7½	8½	6
14	2d	3	3	12	10	3½	4½	7½	8½	6
15	2e	4	4	12	10	5½	7	10	10	6
16	—	2-in. Round		12	10	3-in. Round				6
17	—	3-in. Round		12	10	4-in. Round				6
18	3c	1	1	4	10	1¼	2¼	10	10	6
19	3i	1	1½	4	10	1¼	2¼	10	10	6
20	6b	½	2	8	10	2¼	3½	7½	8½	6
21	3d	1	1	8	10	1¼	2¼	10	10	6
22	3j	1	2½	8	10	3	4	7½	8½	6
23	3k	1	2½	12	10	3	4	7½	8½	6
24	6f	½	3	16	10	3½	4½	7½	8½	6
25	6g	3	3¾	16	10	5½	7	10	10	6
26	3e	1	1	20	10	2	2½	10	10	6
27	3m	1	4	20	10	5½	6½	7½	8½	6
28	6j	2	3⅞	20	10	5½	6½	7½	8½	6
29	6k	3	4¼	20	10	6	7	10	10	6
30	3f	1	1	24	10	2½	3½	10	10	6
31	3n	1	3	24	10	6	7	10	10	6
32	3p	1	4	24	10	6	7	10	10	6
33	3q	1	4¾	28	10	7½	8½	7½	8½	6
34	6n	2	3⅜	28	10	6	7	10	10	6
				SPECIMENS INCLINED 45°						
35	4a	1	1	12	10	1¼	2¼	10	10	6
36	4b	1	2	12	10	2½	3½	7½	8½	6
37	4c	1	3	12	10	3½	4½	7½	8½	6
38	4d	1	4	12	10	4½	5½	7½	8½	6
39	4f	1	4 Sp.	12	10	3½	4½	7½	8½	6
40	4e	1	5	12	10	5½	6½	7½	8½	6
41	4g	1	5U	12	10	5½	6½	7½	8½	6
42	4h	1	3	24	10	6	7	10	10	6
43	—	2	4	12	10	5½	6½	7½	8½	6
44	—	3	5	12	10	7½	8½	7½	8½	6
				SPECIMENS CAST FLATWISE						
45	5a	1	1	12	10	1¼	2¼	10	10	6
46	5b	1	2	12	10	2½	3½	7½	8½	6
47	5c	1	3	12	10	3½	4½	7½	8½	6
48	5d	1	3U	12	10	3½	4½	7½	8½	6
49	5e	1	4	12	10	4½	5½	7½	8½	6
50	5f	1	5	12	10	5½	6½	7½	8½	6
51	5g	2	4	12	10	5½	6½	7½	8½	6
52	5h	3	5	12	10	7½	8½	7½	8½	6
53	—	1	3	24	10	6	7	10	10	6

Table 4

Dimensions of Test Specimens (in Inches)

Volume		*Surface Area*		*Ratio of Volume To Surface Area*		*Weight of Riser*	
Casting cu. in. (*m*)	*Riser cu. in.* (*n*)	*Casting sq. in.* (*o*)	*Riser sq. in.* (*p*)	*Casting cu. in. per sq. in.* (*q*)	*Riser cu. in. per sq. in.* (*r*)	*Per Cent of Casting* (*s*)	*V/A Gradient cu. in. per sq. in.* (*t*)
Vertical Specimens							
120	105	274	144	0.44	0.73	87.5	None
180	144	287	136	0.63	1.06	80.0	0.040
240	192	300	148	0.80	1.30	85.4	0.077
300	240	314	160	0.96	1.50	80.0	0.125
219	192	303	148	0.72	1.30	87.6	——
360	288	328	172	1.10	1.67	80.0	0.154
240	192	300	148	0.80	1.30	85.4	0.077
360	288	334	179	1.08	1.61	80.0	0.076
480	384	368	211	1.30	1.81	80.0	0.076
30	25	249	87	0.12	0.29	83.3	None
60	50	257	94	0.23	0.53	83.3	None
120	105	274	144	0.44	0.73	87.5	None
240	144	308	136	0.78	1.06	60.0	None
360	192	342	148	1.05	1.30	50.5	None
480	375	376	195	1.28	1.92	78.1	None
38	42	79	60	0.48	0.70	110.5	None
85	75	120	81	0.71	0.91	88.2	None
40	105	98	144	0.41	0.73	262.5	None
50	105	99	144	0.51	0.73	210.0	0.050
100	144	185	136	0.54	1.06	144.0	0.056
80	105	186	144	0.43	0.73	131.5	None
140	160	198	142	0.71	1.18	120.0	0.0875
240	168	298	142	0.91	1.18	70.0	——
280	192	373	148	0.75	1.30	68.6	0.076
540	375	458	195	1.18	1.92	69.4	0.021
200	135	450	157	0.44	0.96	67.5	None
500	288	510	180	0.99	1.60	57.6	0.071
588	288	538	181	1.09	1.59	49.0	0.046
725	390	575	228	1.26	1.71	53.8	0.029
240	180	538	171	0.45	1.05	75.0	None
480	390	588	228	0.82	1.71	81.3	0.037
600	390	610	218	0.98	1.79	65.0	0.059
805	384	731	212	1.10	1.81	47.7	0.062
753	390	731	224	1.03	1.74	51.8	0.025
Specimens Inclined 45°							
120	105	274	144	0.44	0.73	87.5	None
180	144	287	136	0.63	1.06	80.0	0.040
240	192	300	148	0.80	1.30	85.4	0.077
300	240	314	160	0.96	1.50	80.0	0.125
219	192	303	148	0.72	1.30	87.6	——
360	288	328	172	1.10	1.67	80.0	0.154
360	288	328	172	1.10	1.67	80.0	0.154
480	390	588	228	0.82	1.71	81.2	0.037
360	288	334	179	1.08	1.61	80.0	0.076
480	384	368	211	1.30	1.81	80.0	0.076
Specimens Cast Flatwise							
120	105	274	144	0.44	0.73	87.5	None
180	144	287	136	0.63	1.06	80.0	0.040
240	192	300	148	0.80	1.30	85.4	0.077
240	192	300	148	0.80	1.30	85.4	0.077
300	240	314	160	1.96	1.50	80.0	0.125
360	268	328	172	1.10	1.67	80.0	0.154
360	288	334	179	1.08	1.61	80.0	0.076
480	384	368	211	1.30	1.81	80.0	0.076
480	390	588	228	0.82	1.71	81.2	0.037

ferrous molds were poured from a No. 90 crucible directly.

22. *Test Castings:* Over 100 specimens were cast for the tests outlined above. Specimens found carrying critical amounts of either taper, height, or thickness—producing sudden and unexpected effects on center-line shrinkage—were remade two to three times to more accurately locate the point of critical transition. The number of specimens cast for each particular test is listed below. Table 4 contains dimension data on the principal types of test castings made. The slab design and the 12-in. height were selected for the specimens used in the subject tests for two reasons: (1) suitability for X-raying on 10x12 film, and (2) the elimination from the investigation of conditions and variables giving rise to local stress raisers, hot spots, and consequent hot and cold tearing. The number and kind of specimens made for each test were as follows:

Test No.	*Specimens Made*	*Figure Numbers*	*Plate Numbers*
1	10	2a-2e inc., 1a	4, 6
2	6	3c-3f inc., 3h, 1a	5, 6
3	4	4a, 5a	7, 8
3	2	—	13, 14
4	8	1b-1f inc.	6
5	6	4b-4f inc., 4h	7
5	6	5b-5c inc., 5e-5h inc.	8
5	2	—	15, 16
6	8	3i-3k inc., 3m-3q inc.	9
6	10	6a-6h inc., 6j	10, 11
7	2	4g-5d	7, 8
8	4	1a	6
9	18	1a-1f, 2a-2d, 4a-4f	4, 6, 7
9	4	5a-5d, inc.	8
10	3	1f, 4f, also flatwise	6, 7
11	4	1a	6, 40
12	2	1a	6
13	1	1a	6
14	3	1a	6, 13, 14
15	6	1a	6
—	10	Miscellaneous	—

TESTS AND METHODS OF TEST

23. Since no physical method exists which can accurately measure and simultaneously distinguish all the void space due to axial shrinkage only, its extent is usually deduced indirectly by one of two standard test methods; either (1) specific gravity tests which, as is known, do not differentiate between dirt trappings, vacancy

due to gas, and vacancy due to shrinkage, or (2) X-ray photography. Both methods of testing were used in the present studies. In the opinion of the Yard, the X-ray method is the more reliable, more sensitive, expeditious, and discriminating for searching out center-line than the specific gravity method.

X-Ray Tests

24. X-ray examination for center-line was performed on ½-in. thick strips, cut longitudinally from two predetermined locations (Plate 23) in each test casting. Unless otherwise expressly stated, all radiographs included in this report were taken on the strip cut from midway between center and gated side. To sharpen the

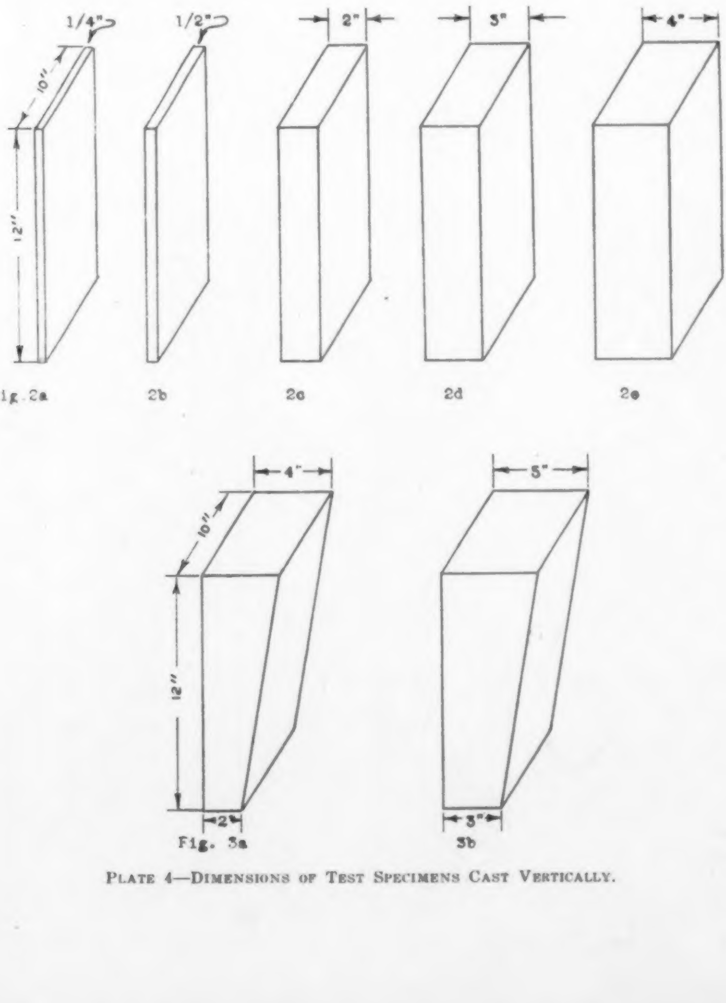


Plate 4—Dimensions of Test Specimens Cast Vertically.

shadow image all interfering surface tool marks were ground smooth. Penetrameters show that a 1 per cent sensitivity was obtained in the tests,—signifying that voids as small as 0.005 in. in size should be discernible to the eye. Closer examination of the radiographs will find registered in the emulsion even the image of the cloth case in which the penetrameters were contained.

25. X-raying was done using a 220 KVA machine operated thusly:

Metal Thickness	½ inch
Target Distance	36 inches
Screen	.005 inch thick lead sheet
Kilovolt Peak	126
Milliampere-seconds	740
Milliamperes	10
Exposure Time	1 min. 14 sec.
Film	Eastman Industrial No-Screen

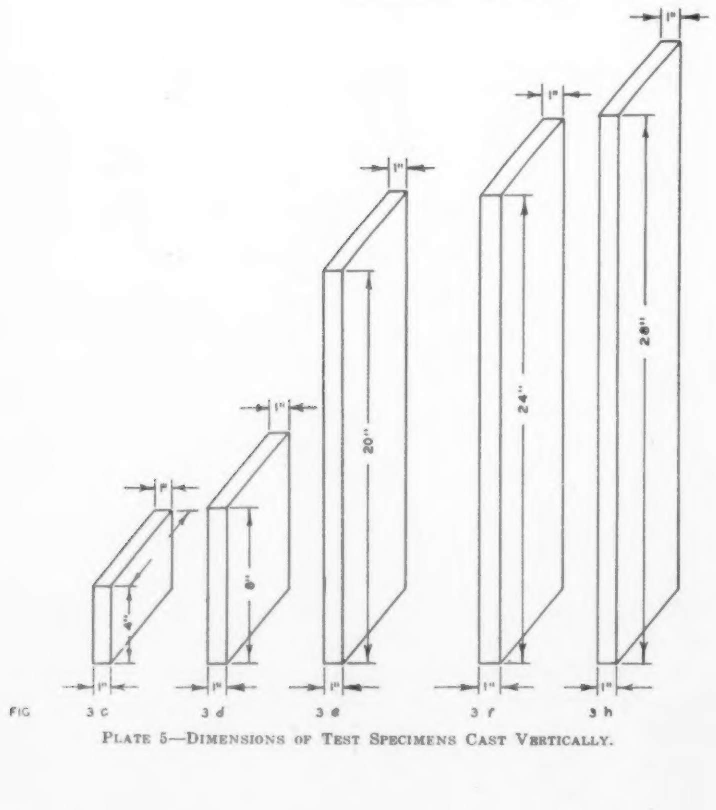


PLATE 5—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

To check the adequacy of the technique, penetrameters (0.005 in.—0.010 in.—0.020 in.—0.030 in.—0.040 in.) were placed on the side of the metal surface toward the radiation. Specimens under ½ in. thick were immersed in copper shot to prevent blurring of the edges. Films were developed for 10 min. at 65°F. in a standard X-ray developing solution containing 20 milligrams potassium iodide per liter. Using the above procedure, densitometer readings on image areas gave Hurter and Driffield values of 0.90 to 1.10.

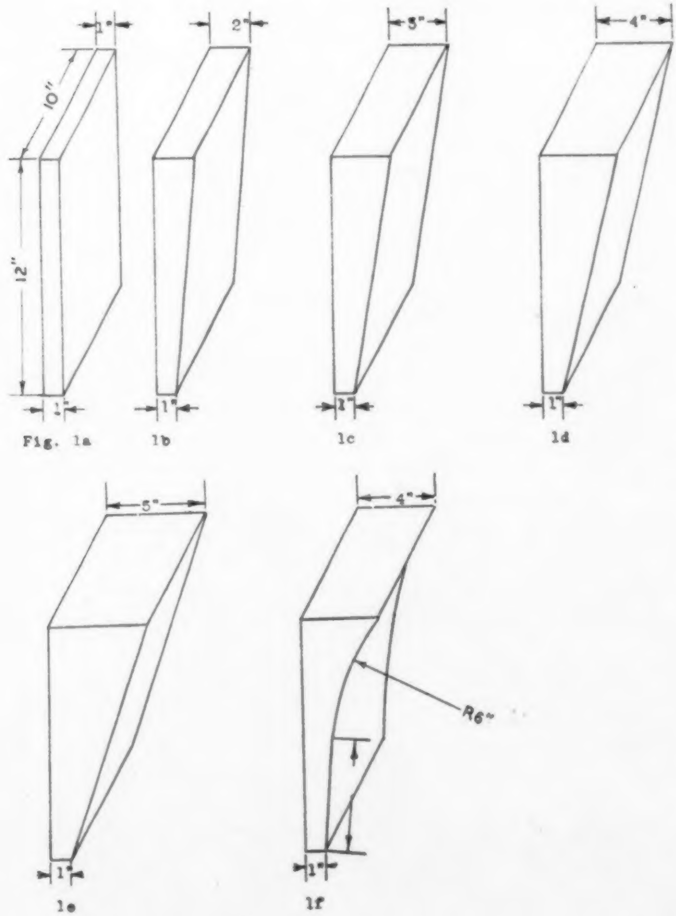


PLATE 6—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

Specific Gravity Tests

26. The extent of center-line shrinkage as determined with specific gravity tests was studied under three different aspects corresponding to three dimensional scales. The first set of specific gravity readings is based on the dimensional scale of the test casting itself, giving the average specific gravity of the entire casting, padding included, in the as-cast, shot-blasted condition; the second set of readings, based on a smaller dimensional scale, records the specific gravity values of finish-machined slabs, padding removed, thus simulating actual, ready-for-service castings (Plate 32); the third set of values indexes the solidity of small cylinders, ⅝ inch

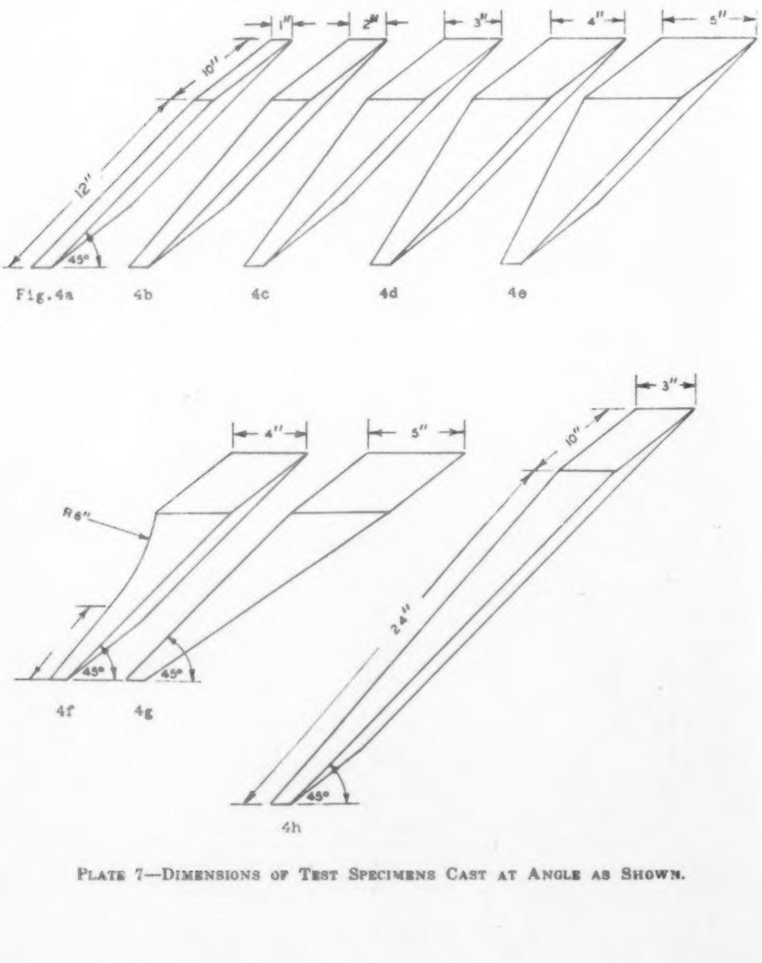


PLATE 7—DIMENSIONS OF TEST SPECIMENS CAST AT ANGLE AS SHOWN.

in diameter by 2 in. long (Plate 33), cut from selected positions in the casting (Plates 24 and 25).

27. In this report specific gravity is defined as the ratio of the mass of a body to the mass of an equal volume of water at 4°C. The weight in air and in water of specimens in the first and second dimensional classes was determined to an accuracy of 1 part in 3200,—scale readable to ⅛ oz.; specimens in the third dimensional class were weighed to an accuracy of plus or minus 0.002 per cent; *i.e.*, with an error of 1 part in 70,000 (balance sensitivity = 0.001 gram). Volume, in all instances, was determined by the water immersion method, distilled water in the case of Class 3 specimens,

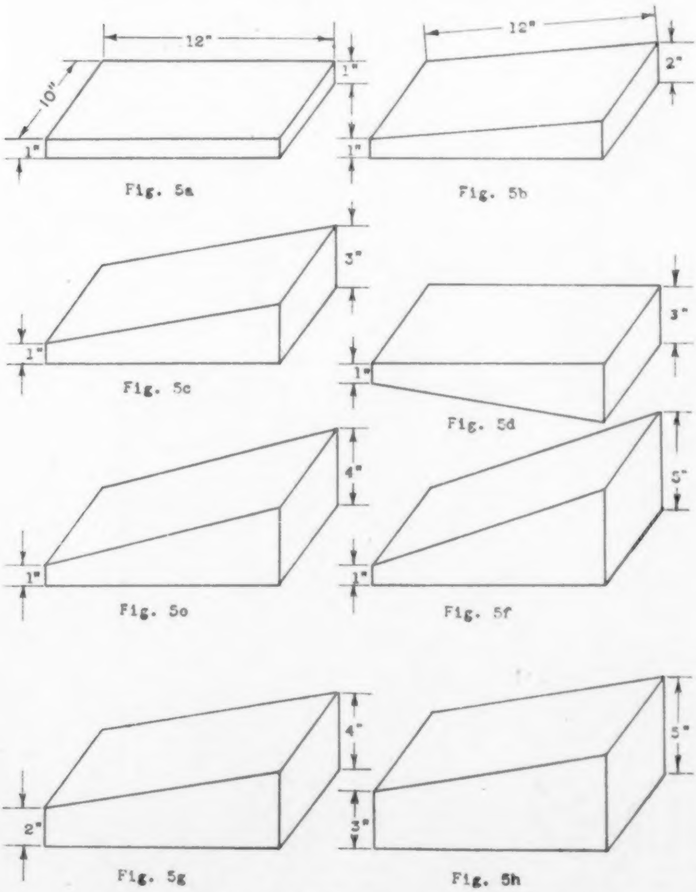


PLATE 8—DIMENSIONS OF TEST SPECIMENS CAST FLATWISE.

and tap water in the case of Class 1 and Class 2 specimens. Cleaning of specimens prior to immersion was done with trichlorethylene, alcohol, and ether. To insure penetration of water into the tiny irregularities in the metal surface, the surface tension of water was broken with a trace (0.1 per cent) of sorbitol laurate wetting reagent.

Tensile and Impact Tests

28. The extent of damage inflicted by center line on physical properties was diagnosed with impact and tensile tests. Tensile

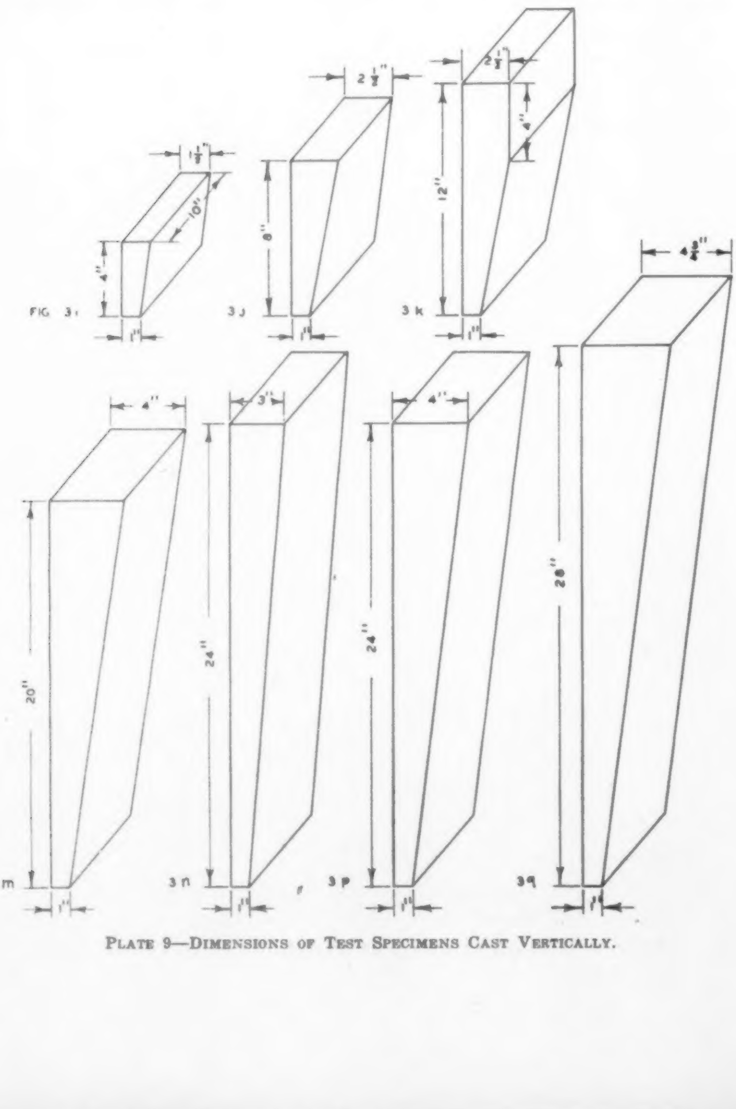


PLATE 9—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

specimens were standard 0.505 in. dia. by 2 in. gage length (Type 1, Appendix II Metals, Part A, of General Specifications for Inspection of Material); impact specimens were .394 inch square, veenotched, Izod type (Fig. 8A of the aforementioned specifications).

DATA OBTAINED AND DISCUSSION OF RESULTS

29. *Test 1:* The influence of section thickness on the formation of center-line is pictured both graphically and radiographically in Plate 26 and Radiographs 1 to 4* inclusive, respectively. They

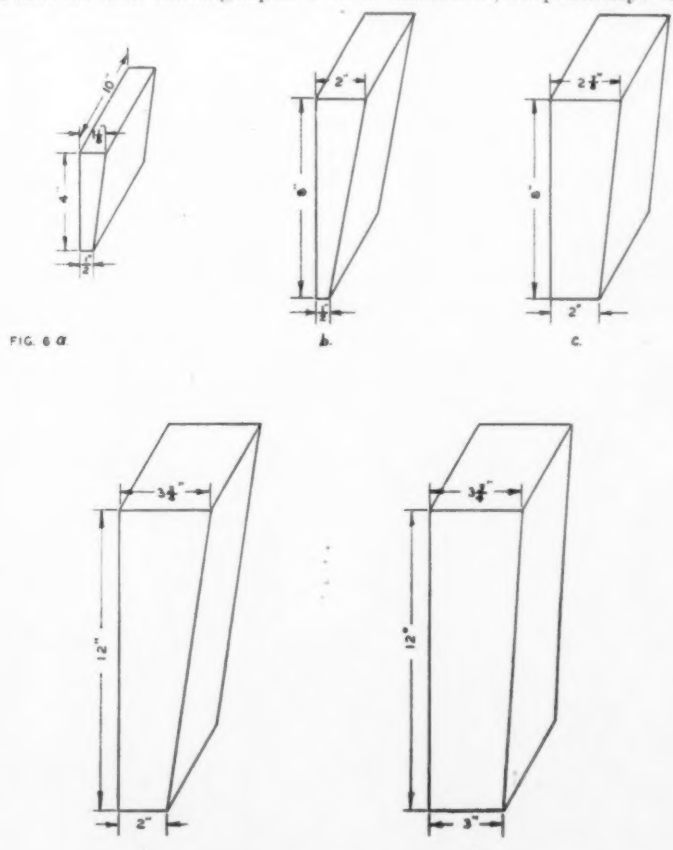


PLATE 10—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

* Radiographs referred to in the text are reproduced on pages 727 to 758.
All radiographs included in this paper were made by X-rays except Radiograph 11, which as the authors explain in paragraph 36 was inserted as a comparison. The authors prefer to use term "Exograph" for radiographs by the X-ray method but to conform to the general practice the term radiograph was adopted by the editors for this preprint.

clearly show that center-line shrinkage in its most pernicious form is severely evident in the ¼, ½, 1, and 2 in. sections; faintly, in the upper half of 3 in. sections; and ever so faintly, in fact scarcely at all, in the topmost metal of 4 in. sections. This progressive elimination of center-line shrinkage in sections of increasing thickness is believed to be due to the correspondingly stronger end and side effects which ultimately suppress all tendency within the metal toward bridging crystallization. The choking effect of bridging dendrites is ever manifest in ¼- to 4-inch thick sections. In these section sizes the nondirectional chilling of the metal by the mold side walls is favorable to their formation. Bridging crystallization is to a large extent responsible for the improper feeding of midwall metal.

30. It is believed that with slight modification, the data of Plate 26 are applicable to round sections as well. According to French[5], "for equal cooling velocity the ratio of the diameter of spheres to the diameter of rounds and the thickness of plates is as 4:3:2, provided the length of the cylinder is at least four times its

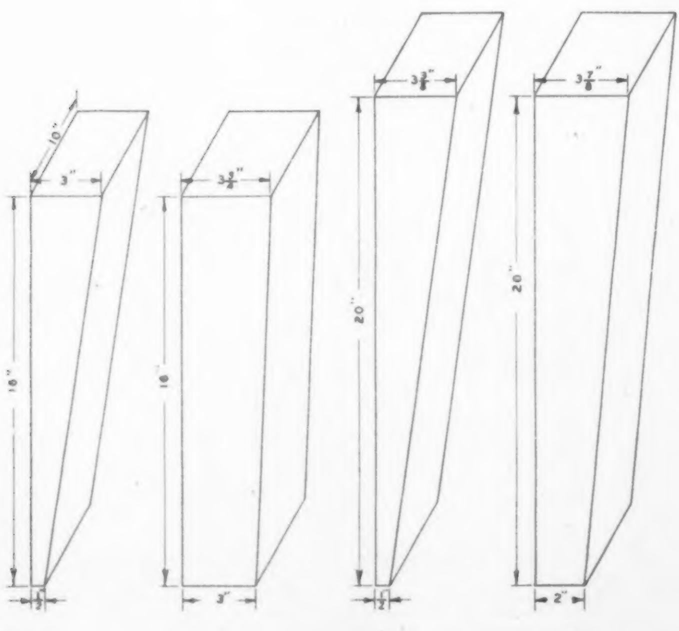


PLATE 11—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

diameter and the length and width are each four times the thickness of the plate.'' Guided by the above, three cylinders, 2, 3, and 4 in. round by 12 in. long, were cast and tested for soundness of center metal. As forecast by the foregoing principle, all three specimens contained axial shrinkage. Two of the specimens are shown in Radiograph 5. The equivalent of a 4-in. plate in freezing, if the principle is extendable to solidification phenomena, should be a 6-in. diameter cylinder. No. 6-in. diameter cylinder was made to further verify this ratio.

31. Several pertinent observations concerning the first four Radiographs merit noting:

> (a) Sections 4 in. thick and 12 in. high, due to the combined action of strong end and side effects, acquire upon freezing temperature gradients which are sufficiently steep to insure progressive solidification of metal and the attendant elimination of internal unsoundness.
>
> (b) Due to strong end and side effects, the line of shrinkage drain is elevated progressively in sections of increasing thickness, the amount of elevation being equal to approximately two times the section thickness.

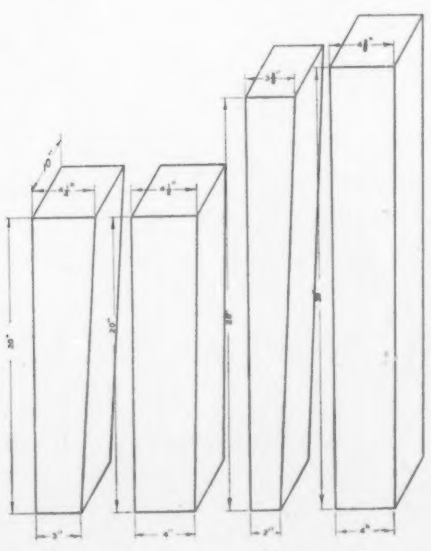


PLATE 12—DIMENSIONS OF TEST SPECIMENS CAST VERTICALLY.

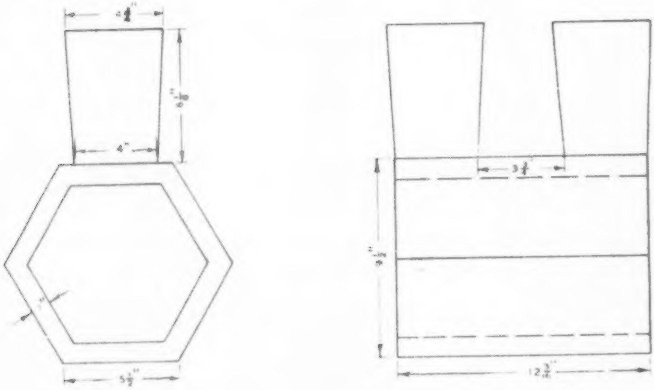


PLATE 13—SKETCH OF REGULAR HEXAGON CASTING UNIFORMLY ONE INCH THICK SHOWING RISERS.

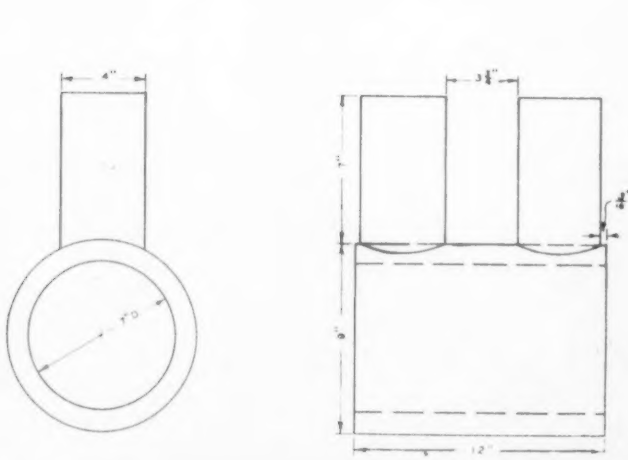


PLATE 14—SKETCH OF CYLINDER CASTING UNIFORMLY ONE INCH THICK SHOWING RISERS.

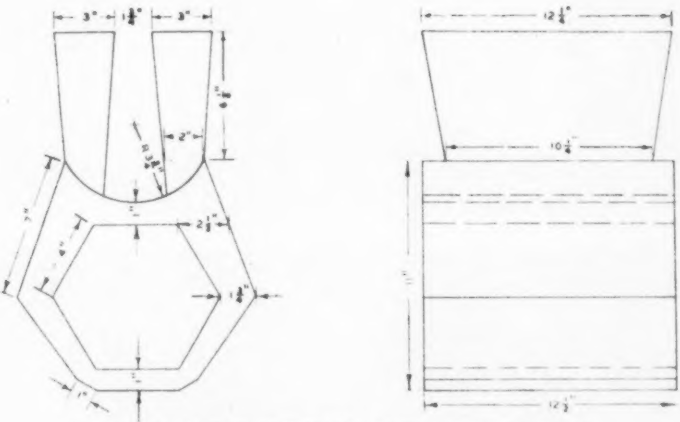


PLATE 15—SKETCH OF HEXAGON, PADDED, SHOWING RISERS.

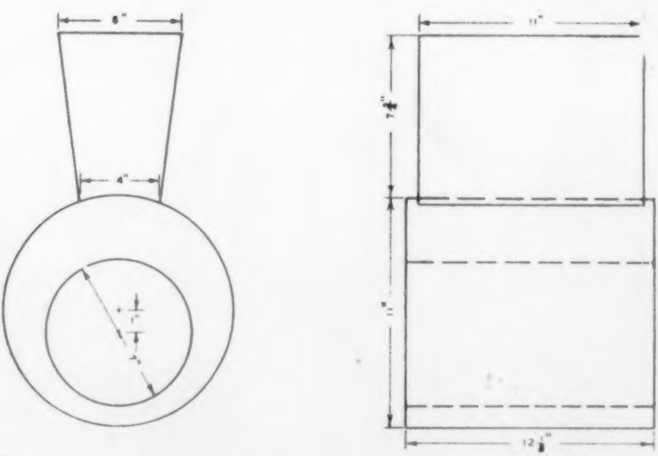
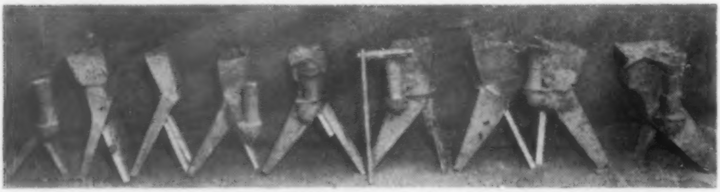
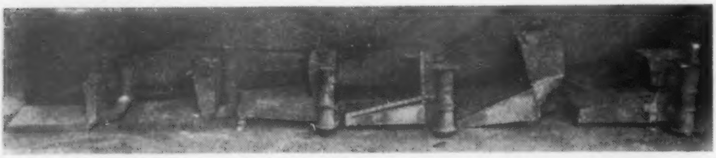
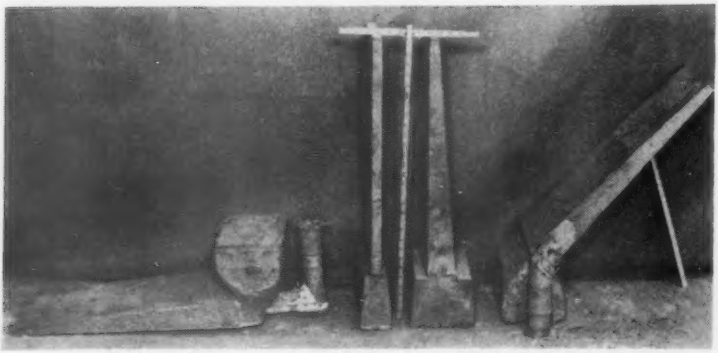


PLATE 16—SKETCH OF CYLINDER, PADDED, SHOWING RISERS.







PLATES 17-20—SPECIMEN CASTINGS SHOWING GATES AND RISERS.

(c) The action of end effect is primarily responsible for the solidity of short chunky sections. The action seemingly fades out at ratios of length to width to thickness of 8:8:1 in steel castings.

(d) Sections 1 in. thick are most susceptible to center-lining with respect to extent and severity. In ¼-in. sections, center-line shrinkage is more restrictive, being confined to the central axis with little lateral spread.

(e) Different but nondirectional rates of freezing exert very little effect on center line formation in sections of constant thickness, neither tending to suppress it in thin, rapidly solidifying castings, nor aggravating it in heavy, slowly solidifying pieces.

32. *Test 2:* All other things remaining equal, the influence of height on unpadded sections, 1 in. thick and having an initial height of 8 in., is negligible on the suppression of center-line shrinkage. In short, there is apparent a marked tendency toward suppression of center-line formation in specimens only in which end effect (bottom chilling and top heading) is strongly assertive. All this is evident in the graph of Plate 27, construction of which is based on data contained in Radiograph 6.

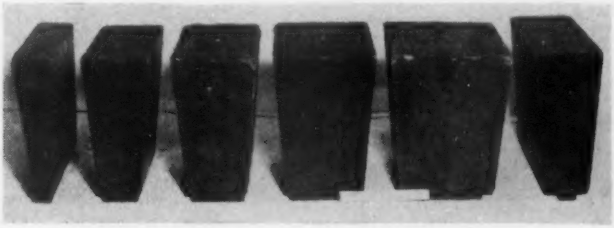


PLATE 21—PATTERNS OF RISERS.

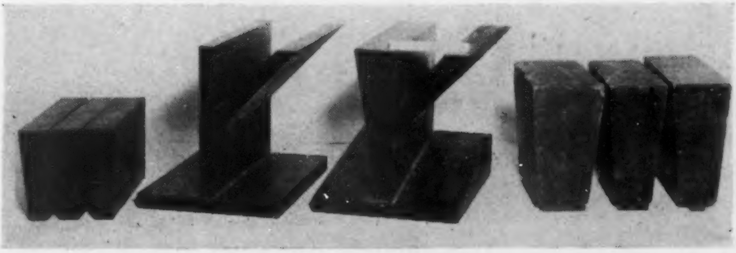


PLATE 22—PATTERNS FOR 3-POSITION WEDGE CASTINGS.

33. *Test 3:* Radiograph 7 pictures center-line shrinkage in uniformly thick sections molded at various inclinations in the mold. It should be noted how the vertices of the shrinkage chevrons tend to plumb perpendicularly downward. In the vertical specimen the vees are erect, their points coincident with the central axis; in the 45° specimen there is a slight lift displacement of the shrinkage toward the top face. Note also how the top branches of some of the vees terminate in gas pockets in the cope subsurface. This crowding of the shrinkage toward the top occurs in more accentuated form in the flat specimen. Lifting of the center-line closer to the cope surface is probably due to the heating of the cope by radiant heat of rising metal and the latent heat of entrapped mold gases. The resulting slow freezing of the cope metal favors the localization of gas and shrinkage defects in that area.

34. There is gleaned one important generalization from the

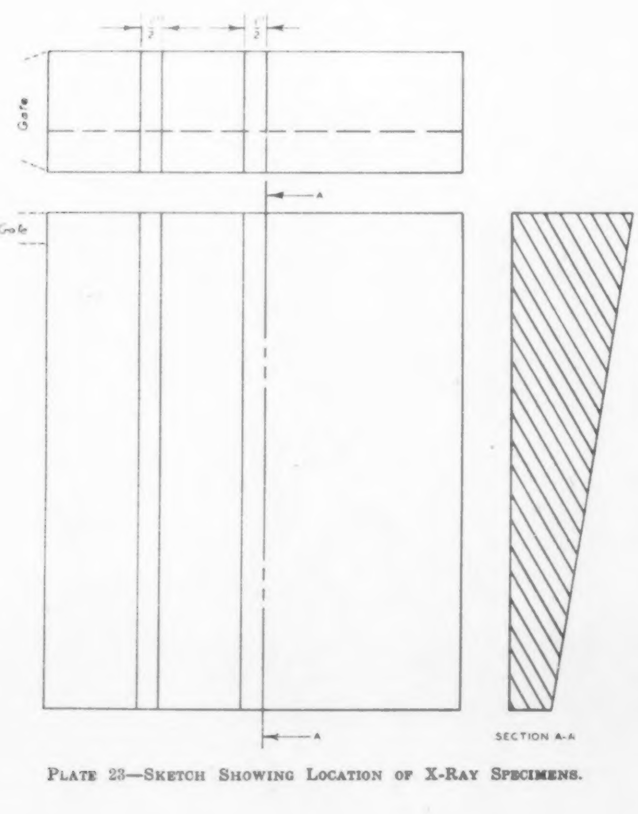


PLATE 23—SKETCH SHOWING LOCATION OF X-RAY SPECIMENS.

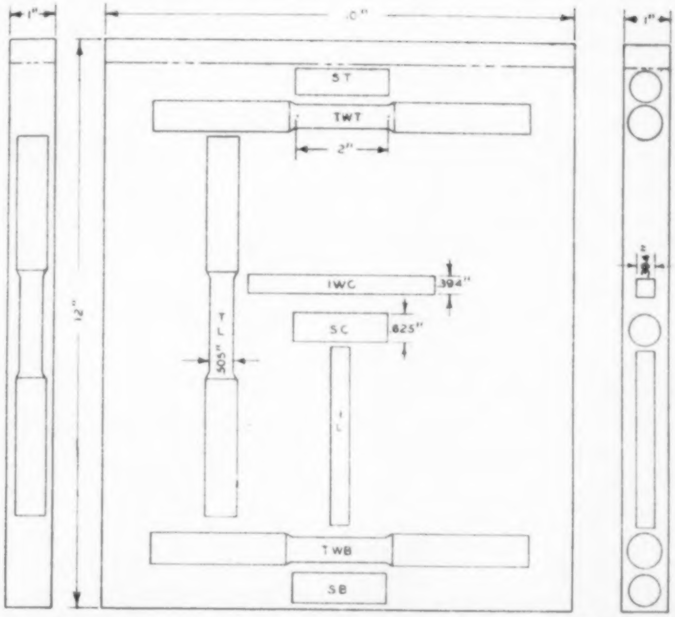


PLATE 24—SKETCH SHOWING LOCATION OF TEST SPECIMENS IN UNIFORMLY THICK SECTIONS.

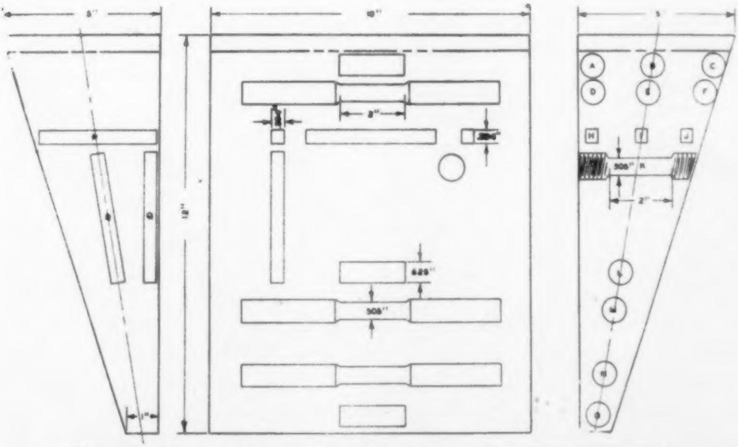


PLATE 25—SKETCH SHOWING LOCATION OF PHYSICAL TEST SPECIMENS.

(A)—STS—Sp. G. Top Straight Side.
(B)—STC—Sp. G. Top Center.
(C)—STT—Sp. G. Top Tapered Side.
(D)—TWTS—Tensile Top Width Straight Side.
(E)—TWTC—Tensile Top Width Center.
(F)—TWTT—Tensile Top Width Tapered Side.
(H)—ISS—Impact Specimen Straight Side.
(I)—ISC—Impact Specimen Center.
(J)—IST—Impact Specimen Tapered Side.
(K)—TA—Tensile Across.
(L)—SCW—Sp. G. Center Width.
(M)—TWC—Tensile Width Center.
(N)—TWB—Tensile Width Bottom.
(O)—SWB—Sp. G. Width Bottom.
(P)—ISA—Impact Specimen Across.
(Q)—ISL—Impact Specimen Lengthwise.
(R)—ISL—Impact Specimen Lengthwise Center.

test, namely: position in the mold alters the geometry of, but does not eliminate interior unsoundness.

35. *Test 4:* Application of taper in increments of 1 in. per ft. to castings 1 in. thick by 12 in. high progressively decreases the amount of internal shrinkage to the point of complete elimination when taper-padded with 2½ to 3 in. of metal per ft. Careful examination of the film in Radiographs 8, 9 and 10 will detect:

(a) Distinct macro-shrinkage in the 1-in. tapered specimen.

(b) Perceptible micro-shrinkage midway between center and top in the 2-in. tapered specimen.

(c) No shrinkage in the 3-in. tapered specimen, top-poured or bottom-poured.

36. It is pointed out that the condition found in the 2-in. tapered specimen is not ordinarily discernible in "gammagraphs" though they be taken with the best possible radiographic technique. Routine gamma-ray inspection, being non-destructive, uses an entirely different set-up procedure. Exposures for castings in the foundry must need be computed for a 1 in. thickness of metal and not a ½ in. thick cross section. Besides, for the same thickness of metal (see Plate 3), face views picture a differently appearing center line, one consisting of a vein-like network of micro-fissures always headed in the direction of the nearest feed head. Face views of 1 in. thickness of metal not only show still less image detail but miss altogether recording the finer porosity. Then, too, it must be remembered that the sensitivity of radium, or its ability to pick up fine discontinuities,—though approximately equal to that of X-rays on 4 in. sections—is considerably less than that of X-rays on ½ in. sections. Radiograph 11 is illustrative of the decreased sensitivity of the gamma-ray technique. So, it is small wonder that shop procedure with its radium, its face views, its thick sections, fails to pick up mild, if not average cases, of center line shrinkage.

37. Although 2 in. of padding may make the metal sufficiently dense for some applications, maximum density of metal will not be realized unless 2½ to 3 in. be used, preferably 2½ in. for top-gated castings and 3 in. for bottom-gated castings. It is indicated in the graph of Plate 28 that to make uniformly solid sections 1 in.

thick by 12 in. high, $2\frac{1}{2}$ to 3 in. of taper per ft. should be used rather than 2 in.,—for a casting having that taper will more than likely be inherently unsound. Where there is any question about the amount of taper necessary for complete solidity, a slight excess rather than a deficiency or a critical quantity should be used. A slight excess of metal will insure soundness in sections whose face contour is locally distorted with accidental bulging or washing of mold walls. Castings carrying critical amounts of taper will generally be sound internally, provided their original contour suffers no change by a localized breakdown of mold. For example, the section pictured in Radiograph 21 contains center-line in the bulges or hot spot areas—places at which the over-all temperature gradient was locally reduced, probably to negation,—thus creating shrinkage. The same section minus the ovoid swellings would ordinarily be solid throughout.

38. *Test 5:* Tests on padded sections variously positioned in the mold confirm results of Test 4 performed on unpadded sections. Approximately the same quantity of center-line shrinkage was found in the flat and 45°, 1-in. tapered specimens, as in vertically cast ones. Radiograph 12 shows two 2-in. tapered specimens, one cast flatwise (F), and the other cast at an angle of 45 degrees (45°). Note that the degree of internal soundness equals that of the vertically cast 2-in. tapered specimen of Radiograph 9.

39. To determine more completely the effect of angularity of section on center-line, hexagonal and circular cylinder castings, padded and unpadded, Plate 13 to 16, inclusive, were cast in the flat position. Unlike conventionally made specimens they were top-gated for procurement of advantageous temperature gradients. The effect of every degree of inclination is manifest in Radiographs 13 to 16, inclusive. Attention is directed to the compactness of metal in the padded designs, and the unsoundness in the unpadded designs.

40. *Test 6:* Since the data of Test 1 revealed a fading out of center-line as section thickness increased, it seemed logical to infer that the amount of taper needed to make sound castings of the heavier sections should likewise correspondingly decrease. It was also believed that taper should decrease with height, for the application of tapers found suitable on 12-in. heights to sections of greater height made those tapers appear disproportionately oversize. To test these beliefs specimens 24 inches high were cast, using reduced amounts of padding and these were made sound with one-

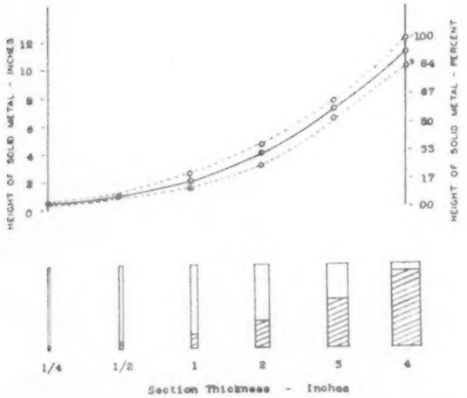


PLATE 26—EFFECT OF SECTION THICKNESS ON CENTER-LINE SHRINKAGE. GRAPH SHOWS HEIGHT OF SOLID METAL IN UNPADDED SECTIONS, 12 IN. HIGH.

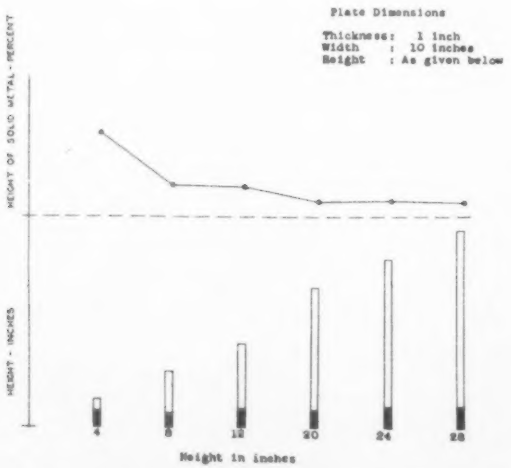


PLATE 27—EFFECT OF SECTION HEIGHT ON CENTER-LINE SHRINKAGE. GRAPH SHOWS HEIGHT OF SOLID METAL, IN PER CENT, OBTAINABLE IN ONE-IN. THICK SECTIONS.

half the padding in inches per inch used on the 12-in. high specimens. The tests were continued until several specimens of each thickness,—namely, ½, 1, 2, 3, and 4 in.,—were cast 4, 8, 16, 20, 24, and 28 in. high padded with tapers of irreducibly minimum size but still adequate to produce sound metal. Foregoing minimum sizes had been previously determined in part by trial and error on actual production castings.

41. The sketches in Plate 29, by the horizontal distance separating the vertical side lines at any given height and for any given thickness of section, indicate the taper needed in inches to free that section from center-line unsoundness. Plate 30 contains the same information except that the required taper is expressed in inches per linear inch of section. In connection with the foregoing graphs one is reminded that the test results are, like those of other materials, liable to a certain amount of scatter due to the chance combination of minor variables which are difficult to control in production. The broken lines of Plates 26 and 28 show the extent of this scatter; namely, plus or minus 5 per cent. Some of the important wedge castings used in constructing the graphs of Plates 29 and 30 are pictured radiographically in Radiographs 17 to 24, inclusive.

42. Surprising to note is the fact that the 12- to 14-in. heights require more padding in inches per inch than either the lower or higher specimens. The probable explanation for this may be that for specimens under 12 in., strong end and side effects aid taper in the establishment of the desired temperature gradient and with it the consequent prevention of bridging; that for specimens over 12 in., increased ferrostatic head breaks through bridging crystallization and thus helps compact the metal. In addition, self mold preheating by inflowing metal and by radiant heat of rising metal may also be a contributory cause.

43. A feature of particular interest is that the volume per unit of surface area per linear inch of either height or length is definitely related to the integrity of the metal after solidification. The V/SA/Inch gradient (Column "t", Table 4) required to make solid sections is not a fixed, constant value but a fluctuating one varying with section height and section thickness. A family of straight parallel lines, one for each thickness of metal, can be obtained if height be plotted against the V/SA/Inch gradient on rectangular coordinates. Because of its limited practical worth, no

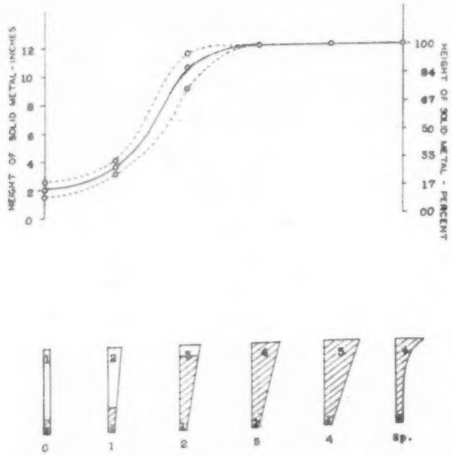


PLATE 28—EFFECT OF TAPER ON CENTER-LINE SHRINKAGE. GRAPH GIVES HEIGHT OF SOLID METAL OBTAINED IN SECTIONS 12 IN. HIGH, ONE IN. THICK AND PADDED AS INDICATED.

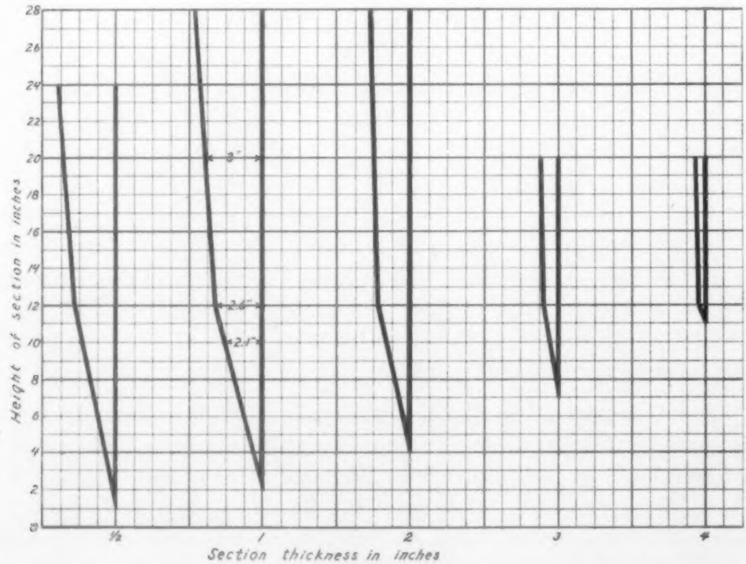


PLATE 29—EFFECT OF TAPER ON CENTER-LINE SHRINKAGE. GRAPH SHOWS AMOUNT OF TAPER REQUIRED TO OBTAIN METAL SOLIDITY IN SECTIONS OF VARIOUS HEIGHT AND THICKNESS. REQUIRED TAPER IN INCHES FOR ANY SECTION HEIGHT AND THICKNESS IS EQUAL TO THE HORIZONTAL WIDTH BETWEEN THE LINES IN THE FIGURES, AS ILLUSTRATED IN THE ONE-IN. THICK SECTION.

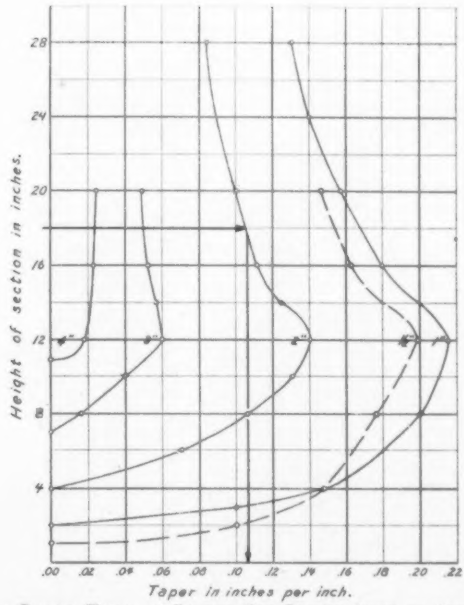


PLATE 30—GRAPH SHOWS TAPER IN INCHES PER LINEAR INCH OF SECTION REQUIRED TO OBTAIN SOLID METAL IN SECTIONS OF VARIOUS HEIGHT AND THICKNESS. THIS ILLUSTRATION SHOWS 1.91 IN. (0.106 x 18) PADDING IS REQUIRED FOR A 2-IN. THICK SECTION BY 18 IN. HIGH.

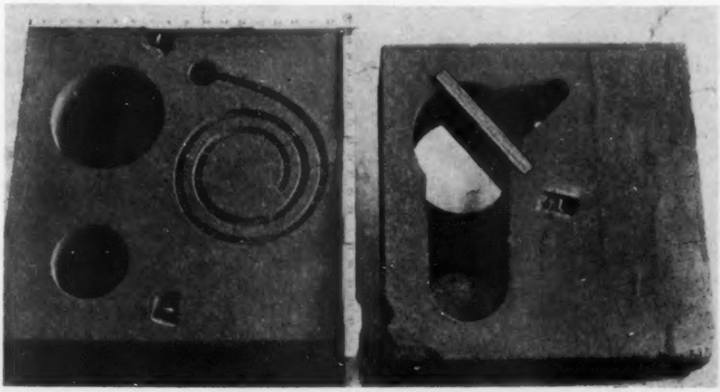


PLATE 31—MOLD FOR FLUIDITY SPIRAL.

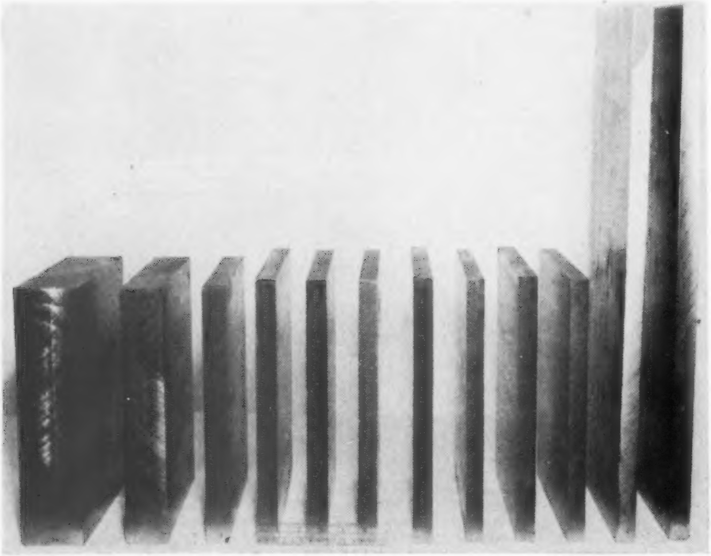


PLATE 32—CAST STEEL PLATE SPECIMENS MILL-MACHINED ON ALL FACES AND EDGES.

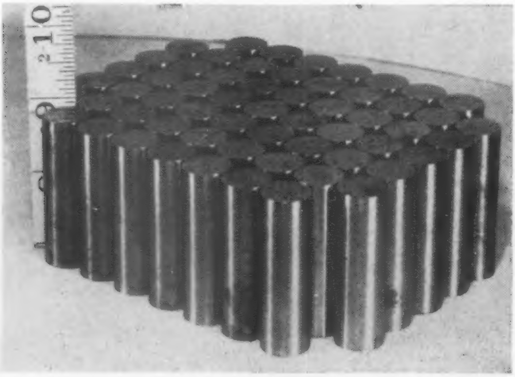


PLATE 33—SPECIFIC GRAVITY SPECIMENS.

attempt has been made to include it among the graphs. The relation is noted as a matter of purely academic interest.

44. From Tests 4 and 6 it is thus learned that a definite difference in heat content between every successive point on a line from the far to the near end of the casting is essential for the making of solid metal. It is further learned from Test 6 that the value of this heat differential is a variable quantity, changing with section thickness and section height. By way of illustration, the value of this heat differential for a pure iron plate, 1 in. thick x 12 in. high wedged with 2½ in. of metal per ft. and cast at 2800°F., is approximately as given below. Note the steepness of the heat gradient.

BTUs in Each Inch of Taper*

	Across 1 in. of width	*Across 10 in. of width*
Bottom Inch	15.3	153
2nd inch	47.5	475
3rd inch	79.7	797
4th inch	111.9	1119
5th inch	144.1	1441
6th inch	176.3	1763
7th inch	208.5	2085
8th inch	240.7	2407
9th inch	272.9	2729
10th inch	305.1	3051
11th inch	340.4	3404
12th Top Inch	369.5	3695

45. *Test 7:* In Test 5 of this study it was discovered that soundness of metal is obtained in wedged castings irrespective of the position occupied by them in the mold. Therefore, it matters little whether padding is applied to the top side or to the bottom side so long as a sufficiency of padding is used. By padding the top side, however, the vertical component of gravity will be greater which in turn should react favorably on feeding; then, too, top padding, particularly with reference to inclined specimens, will weigh less than bottom padding. For it is a fact of elementary geometry

* A.S.M. Handbook, 1936 Edition. Calculations are based on a value of 540 B.T.U.s per pound for iron at 2800°F.

that a right angle pad placed atop an inclined specimen has a shorter hypotenuse than the same pad placed on the under side. Whenever it is possible to pad on the top face, it is therefore advantageous to do so.

46. *Test 8:* One 1 ton heat of steel was dedicatorily consigned to the study of temperature effects on center-line formation. The heat was tapped at 3200°F. and poured alternately into fluidity spirals patterned after the Naval Research Laboratory large fluidity test piece (7, Plate 31) and into 1-inch thick X-ray test pieces similar to that of Fig. 1a, Plate 6, with 2 fluidity spiral channels attached, one to the top and the other to the bottom of the test piece.

47. Table 5 attests to the fact that the influence of fluidity on

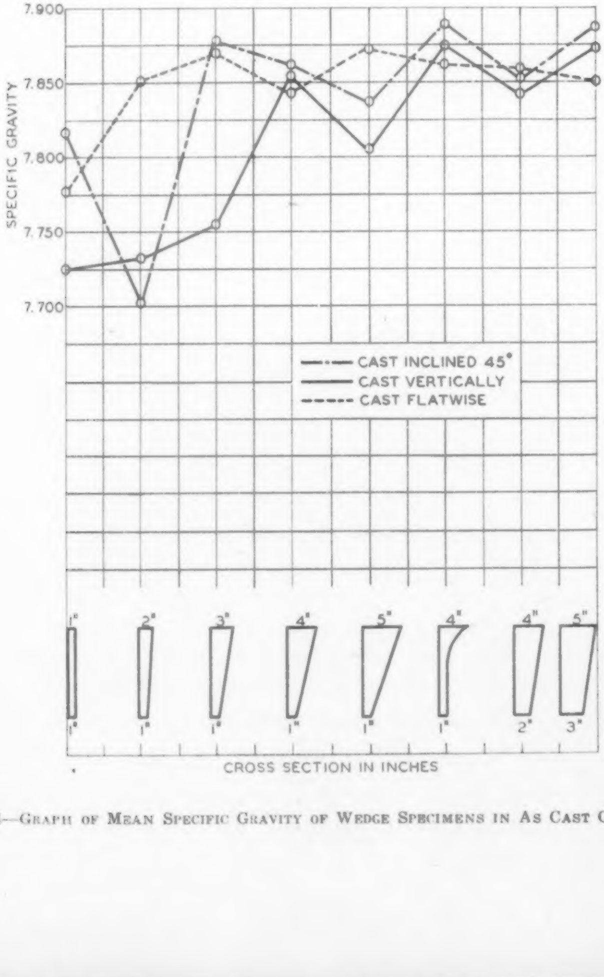


PLATE 34—GRAPH OF MEAN SPECIFIC GRAVITY OF WEDGE SPECIMENS IN AS CAST CONDITION

center-line formation is inappreciably small, at best, difficult of precise determination with the methods used herein and within the temperature range studied. Radiograph 25 shows the extent of center-line shrinkage obtained at the various temperatures.

48. *Test 9:* Machined specimens such as those shown in Plate 32 were tested hydrostatically for strength and porosity at 10,000 lb. per sq. in. pressure. Leaks developed in all 1 inch thick, unpadded specimens. Those cast vertically leaked the least; inclined specimens, slightly more; flat specimens, the worst. Pads of 1 in. per foot, when machined off, also resulted in leaky castings. No leaks were manifest in the remainder of the specimens.

49. Supplementing the X-ray density studies of cast steel are the specific gravity tests. As has already been stated, three distinctly different kinds of test specimens were employed:

(1) Foundry-cleaned, as-cast, taper-included specimens (Plates 17 to 20, inclusive).

(2) Same specimens with taper cut away and milled (Plate 32).

(3) Lathe-turned, micrometer-sized, 0.625 in. dia. specimens by 2.000 inches long (Plate 33).

50. The graph of Plate 34 shows the variations in specific gravity of whole, as-cast wedges molded in the flat, 45°, and vertical positions. Specific gravity, it will be remembered, was computed as the ratio of the mass of the body to the mass of an equal volume of water at 4°C. Note the consistently high values and the tendency toward leveling off when tapers of 3 in. per ft. and over are used. The graphs corroborate with remarkable nicety all X-ray findings as to the influence of taper and position in the mold on the soundness of cast steel.

51. Slightly lower specific gravity values were obtained on the

Table 5

TEMPERATURE EFFECTS ON CENTER-LINE SHRINKAGE
IN CAST SPECIMENS 1 IN. THICK BY 10 IN. WIDE BY 12 IN. HIGH

Specimen Number In Order of Pouring	*Length of Center-line in Test Piece In.*	*Length of Individual Spiral Channel In.*	*Length of Attached Spiral Channel In.*	*Optical Pyrometer Temperature Reading °F.*
1	9½	37¼	29¾	3130
2	9¼	28¼	25	2990
3	10	19¾	20½	2850
4	8	14	15¼	2780

same specimens after they had been machined as is apparent in the curves of Plate 35. This slight but general drop in specific gravity is probably due, among other causes, to: (1) loss of chill consisting of tightly packed, fine chill crystals; and (2) increased error ratio obtained from weighing lighter specimens.

52. Of the two, the first has the less effect. For the ⅝ in. diameter specimens, specially those taken from deep within the castings, serve to substantiate the fact that central metal can also be of the same high order of density as surface metal. The removal of chill metal may or may not reduce the overall specific gravity of the remaining metal. In actual practice it is seldom that more than 50 per cent of the original chill metal is removed. In applying padding the following axiom is rigidly adhered to: Pad one side only, the side easiest to get at, preferably the side which is to be machined.

53. The specific gravity values for small specimens, ⅝ in.

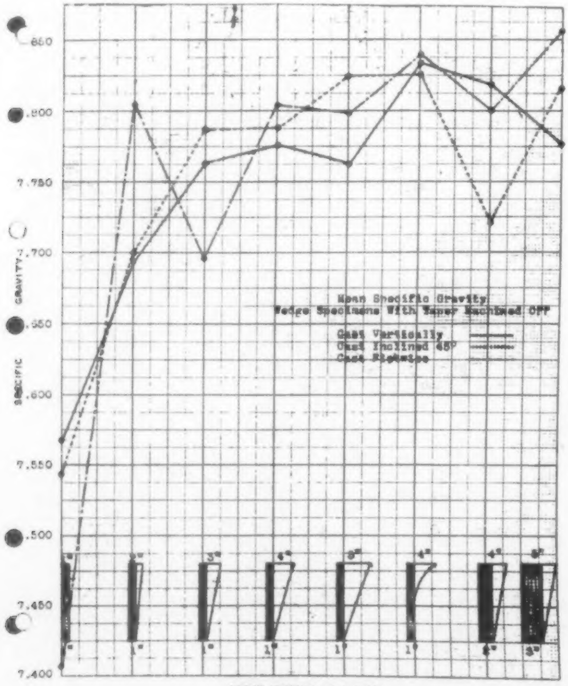


PLATE 35—GRAPH OF MEAN SPECIFIC GRAVITY OF WEDGE SPECIMENS WITH TAPER MACHINED OFF.

Table 6

SPECIFIC GRAVITY MEASUREMENTS
MACHINED SPECEMENS—5/8 IN. DIA. BY 2 IN.

Number[1]	*Sp. Gr.*	*Number*	*Sp. Gr.*
1 ST	7.790	37 SC	7.834
1 SC	7.770	37 SB	7.835
1 SB	7.817	38 STC	7.833
2 ST	7.826	38 STC	7.834
2 SC	7.826	38 SC	7.832
2 SB	7.839	38 SB	7.834
3 STT	7.865	39 STC	7.836
3 STC	7.838	39 SC	7.831
3 SC	7.836	39 SB	7.835
3 SB	7.838	40 STC	7.833
4 STC	7.836	40 STS	7.834
4 STT	7.833	40 SC	7.832
4 SC	7.838	40 SB	7.835
4 SB	7.838	41 STC	7.830
5 STC	7.838	41 SC	7.835
5 SC	7.803	41 SB	7.836
5 SB	7.839	42 ST	7.914
6 STC	7.834	42 SC	7.827
6 STS	7.840	42 SB	7.837
6 STT	7.850	43 STC	7.633
6 SC	7.837	43 SC	7.837
6 SB	7.839	44 STC	7.829
8 STC	7.836	44 SC	7.833
8 SC	7.837	44 SB	7.825
8 SB	7.837	45 ST	7.824
9 STC	7.836	45 SC	7.804
9 STS	7.838	45 SB	7.804
9 SC	7.838	46 ST	7.834
9 SB	7.839	46 SC	7.828
30 ST	7.720	46 SB	7.837
30 SC	7.718	47 STC	7.833
30 SB	7.866	47 SC	7.833
31 ST	7.837	47 SB	7.835
31 SC	7.825	48 STT	7.833
31 SB	7.836	48 STC	7.834
35 ST	7.745	50 STC	7.834
35 SC	7.791	50 STT	7.832
35 SB	7.835	50 SC	7.837
36 ST	7.821	50 SB	7.833
36 SC	7.823	51 STC	7.833
36 SB	7.836	51 SC	7.832
37 STC	7.825	51 SB	7.835

[1] The number identifies the test piece according to Table 4; the letters, according to Plates 24 and 25.

Table 7

PHYSICAL PROPERTIES[1]

No.	Casting Size	Position[2]	Location of Test Specimens[4] Tensile	Impact	Sp. Gr.	Tensile Strength PSI	Yield Point PSI	Elong. in 2 in. %	Red. in Area %	"Bird-eyes" in Fracture	Izod Impact Foot-Pounds L.A.[3]	S.A.[3]	Sp. Gr.
						UNPADDED SPECIMENS							
1	1x1	V-Bottom	24-TWB	24-TWB	24-SB	68000	44500	24.0	35.6	2	43	44	7.82
35	1x1	A-Bottom	24-TWB	——	24-SB	70250	48000	28.0	40.5	None			7.84
45	1x1	F-Bottom	24-TWB	——	24-SB	72250	49500	29.0	45.7	None			7.84
1	1x1	V-Top	24-TWT	24-IWC	24-ST	70750	50000	20.0	28.8	2	24-30	32-34	7.79
35	1x1	A-Top	24-TWT	——	24-ST	70250	46000	19.5	28.8	3			7.75
45	1x1	F-Top	24-TWT	——	24-ST	68250	45250	13.0	22.7	2			7.82
						PADDED SPECIMENS							
1	1x1	V-Length	24-TL	24-TL	24-SC	55000	45500	8.0	17.8	Streaky	28-31	26-28	7.77
35	1x1	A-Length	24-TL	——	24-SC	52250	44000	7.5	16.3	Streaky			7.79
45	1x1	F-Length	24-TL	——	24-SC	51500	44500	8.0	17.4	Spongy			7.80
2	1x2	V-Top	24-TWT		24-ST	67500	43500	16.5	27.5	2			7.83
36	1x2	A-Top	24-TWT		24-ST	66250	44750	10.0	16.3	3			7.82
46	1x2	F-Top	24-TWT		24-ST	69750	47250	25.0	32.5	5			7.83
3	1x3	V-Top	25-E		25-B	67500	45250	22.5	30.2	2			7.86
37	1x3	A-Top	25-E		25-B	65750	46000	11.0	24.1	1			7.82
37	1x3	A-Bottom	25-N		25-O	72750	48000	29.5	42.5	None			7.84
47	1x3	F-Top	25-E		25-B	69750	47250	22.0	28.2	2 Tiny			7.83
5	1x4	V-Top-C	25-E		25-B	68500	43750	22.0	26.8	3			7.84
4	1x4	V-Top-T	25-F		25-C	70000	46375	22.5	28.2	3 Tiny			7.54
4	1x4	V-Top-S	25-D		25-A	71000	48250	29.0	44.0	None			7.83
4	1x4	V-Top-C	25-E		25-B	68375	45625	21.5	27.5	7			7.83
4	1x4	V-Length	24-TL	25-R	25-L	70250	46625	21.0	26.5	2	38	40	7.84
4	1x4	V-Bottom	25-N		25-O	71000	47000	29.0	45.5	None			7.84
4	1x4	V-Across		25-P							31	32	

[1] Cast wedges annealed at 1650°F. for 4 hrs.

[2] Legend: **V — Vertical**, **A — Inclined 45°**, **F — Flat**; C — Center, **S — Straight Side**, **T — Tapered Side**, O — Outside

[3] Notched parallel to: **L.A. — Long Axis**, **S.A. — Short Axis**

[4] See Plates 24 and 25 for location of specimens.

Table 7

(Continued)

PHYSICAL PROPERTIES[1]

PADDED SPECIMENS

No.	Casting Size	Position[2]	Tensile	Location of Test Specimens[4] Impact	Sp. Gr.	Tensile Strength PSI	Yield Point PSI	Elong. in 2 in. %	Red. in Area %	"Bird-eyes" in Fracture	Izod Impact Foot-Pounds L.A.[3]	Izod Impact Foot-Pounds S.A.[3]	Sp. Gr.
6	1x5	V-Bottom	25-N		25-O	70125	45750	18.5	26.2	3			7.84
6	1x5	V-Center	25-M	25-Q	25-L	68500	44750	21.0	26.8	7	42	42	7.84
6	1x5	V-Top-S	25-D	25-I	25-A	70500	44750	29.0	43.4	None	38-39	40-43	7.84
6	1x5	V-Top-T	25-F	25-J	25-C	69250	46000	20.0	25.8	None	37	42	
6	1x5	V-Top-C	25-E		25-B	66500	43750	15.0	24.1	4			7.83
6	1x5	V-Across		25-P							40	41	
40	1x5	A-Bottom	25-N		25-O	71000	47000	29.0	45.5	None			7.84
40	1x5	A-Center	25-M		25-L	70000	45000	17.0	22.0	12			7.83
40	1x5	A-Top-S	25-D		25-A	69250	43750	23.0	29.8	3 Tiny			7.83
40	1x5	A-Top-C	25-E		25-B	67750	46250	14.0	19.8	9			7.83
50	1x5	F-Bottom	25-N		25-O	72000	46000	29.5	42.3	None			7.83
50	1x5	F-Center	25-M		25-L	69500	44750	15.0	21.0	7			7.84
50	1x5	F-Top-T	25-F		25-C	70000	44250	16.5	24.1	2			7.83
9	3x5	V-Bottom	25-N		25-O	68500	42000	24.0	32.2	2 Tiny			7.84
9	3x5	V-Top-C	25-E		25-B	65500	45500	12.0	19.2	4			7.84
9	3x5	V-Top-S	25-O		25-A	69500	47250	20.0	24.8	11			7.84
9	3x5	V-Across	25-K		——	72000	42500	33.0	42.0	3 Tiny			——
9	3x5	V-Across	25-K		——	68000	44500	12.0	16.0	5			7.84
9	3x5	V-Length	——		——	66000	45250	13.5	20.0	2			——
52	3x5	F-Bottom	25-N		25-O	71250	45750	26.0	35.4	12			7.83
52	3x5	F-Top-C	25-E		25-B	66750	45250	15.0	23.1	9			7.83

[1] Cast wedges annealed at 1650°F. for 4 hrs.

[2] Legend: V — Vertical; A — Inclined 45°; F — Flat; C — Center; S — Straight Side; T — Tapered Side; O — Outside

[3] Notched parallel to: L.A. — Long Axis; S.A. — Short Axis

[4] See Plates 24 and 25 for location of specimens.

round by 2 in. long, taken from pre-selected areas in the test casting—top, center, bottom (see Plates 24 and 25)—are shown plotted and tabulated in the graphs of Plates 36, 37, 38, and Table 6 respectively. Commenting briefly on these results, it is seen that the bottom areas are consistently the densest in all specimens and in all positions. Top and center areas are approximately of equivalent density in all sections padded with 2-inches and more of taper per foot. Vertically cast sections appear to have a slightly denser metal structure than either flat or inclined sections. Unpadded material, it will be noted, is of erratic as well as of low density.

54. Plate 39 presents information on the relative effect of mass or section thickness on the density of steel. Applying the same taper; namely, two in. per ft., to sections 1, 2, and 3 in. thick, produces little, if any, change in the density or specific gravity of the material. Here again the vertical specimens show the highest values; the inclined specimens, the greatest scatter; the flat specimens, values intermediate between those of vertical and inclined specimens with respect to both scatter and range of value.

55. When present in severe form as in 1-in. sections center-line exerts a most damaging effect on mechanical properties. The extent of damage dealt the metal becomes apparent on comparing the properties of test specimens on the same metal in the sound and unsound condition: *i.e.*, bottom and top metal, Table 7. When tested in the direction of the width of the plate, center-line affects principally the elongation and reduction in area values; when tested in the direction of the long axis or the length, its damaging influence was evinced with most telling force,—reducing strength and ductility by approximately 20 and 50 per cent, respectively. Properly padded specimens (3 in. per ft.) show not only greatly improved tensile properties, but properties fairly uniform in all directions. In all instances the outside skin metal to a depth of approximately 5/8 in. tested consistently higher in elongation and reduction in area than the center metal. The center metal of fairly heavy sections (5 in. thick) is comparatively free from directional properties.

56. Regarding the influence of center-line shrinkage on notch sensitivity, Table 7 shows comparatively lower notch bar values for center-lined specimens than for sound, solid specimens. To discover notch sensitive directions due to possible unidirectional grain orientation effects, impact specimens were severally notched on each of their four faces. No consistent, nor significantly large

differences in notch sensitivity due to any latent disposition in the steel to crystallize in certain fixed positions were found either in padded or unpadded sections.

57. *Test 10:* The geometry of pad design is not limited to straight line tapers. There are many other equally effective kinds of taper: curvilinear, broken rectilinear, or combination of both, which can obtain as high a degree of metal integrity as regular tapers. One such pad is shown in Figure 1f, Plate 6, and Radiograph 20. This design is equivalent in effect to the 3-in. taper per ft., yet it weighs only 27-30 per cent as much as the 3 in. per ft. taper. The advantage of decreased weight, however, is offset by other economic considerations.

58. *Test 11:* Four steel plates, dimensioned after Fig. 1a, Plate 6, that is, 1 in. thick x 10 in. wide x 12 in. high, were cast and fed from two blind risers, one on either side, made according to the Dodge method[8]. Plate 40 pictures a casting with risers, necks,

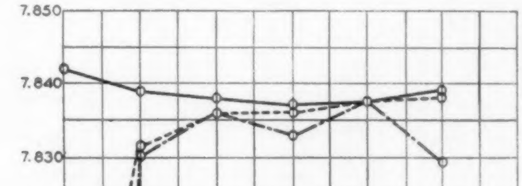


PLATE 36—GRAPH OF SPECIFIC GRAVITY OF ⅝ IN. DIAMETER BY 2 IN. SPECIMENS—SPECIFIC GRAVITY "AT A POINT" OF WEDGE SPECIMENS CAST VERTICALLY.

and ingate attached; Plate 41 is a photograph of blind risers cut in two. It will be observed that the minimum ratio of 1:2:3 of thickness of casting to neck to riser was adequately maintained.

59. The volume to area relationship of the blind and open risers used for feeding above castings are given below:

Kind of Riser	*Volume cu. in.*	*Area sq. in.*	*V/SA cu. in./– per sq. in.*	*Weight– per cent of casting*
Open	105.0	144	.73	87.5
Blind, single	87.5	110	.80	73.0
Blind, double	175.0	220	.80	146.0

From the standpoint of volume as well as V/SA ratio; namely, quantity of metal and heat storage capacity, respectively, the two blind risers have a decided advantage over the open riser. Yet they do not produce a denser casting. X-ray examination of rep-

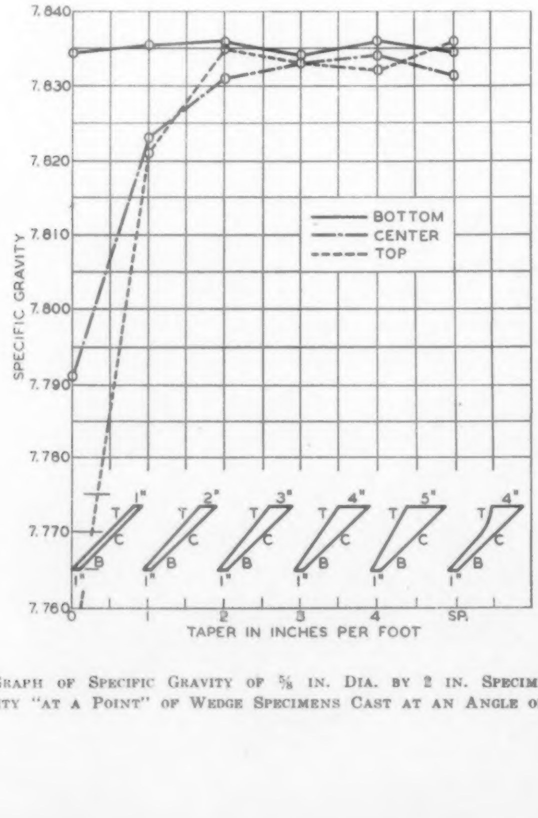


PLATE 37—GRAPH OF SPECIFIC GRAVITY OF ⅝ IN. DIA. BY 2 IN. SPECIMENS—SPECIFIC GRAVITY "AT A POINT" OF WEDGE SPECIMENS CAST AT AN ANGLE OF 45°.

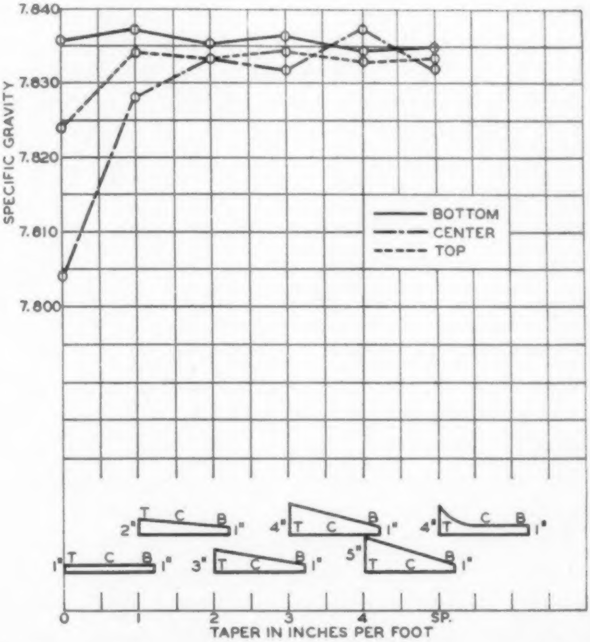


PLATE 38—GRAPH OF SPECIFIC GRAVITY OF 5/8 IN. DIA. BY 2 IN. SPECIMENS—SPECIFIC GRAVITY "AT A POINT" OF WEDGE SPECIMENS CAST FLATWISE.

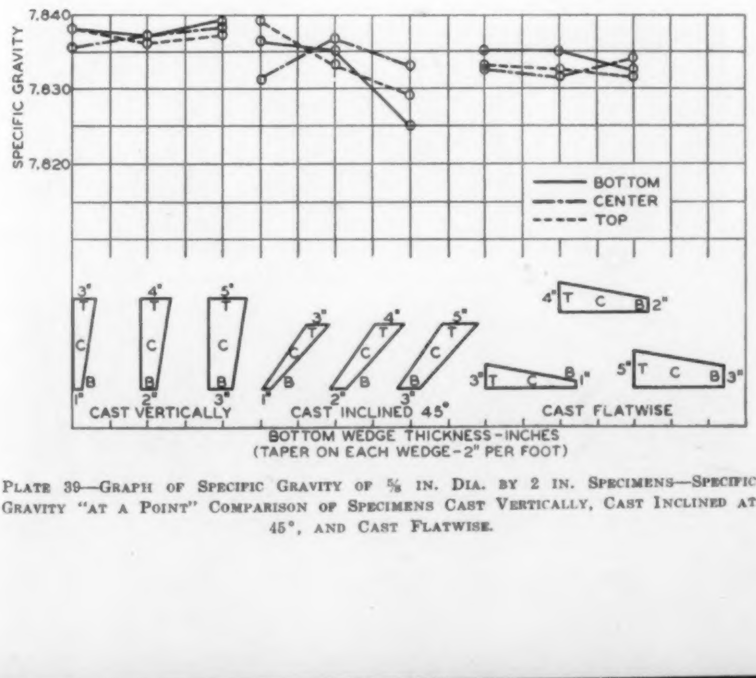


PLATE 39—GRAPH OF SPECIFIC GRAVITY OF 5/8 IN. DIA. BY 2 IN. SPECIMENS—SPECIFIC GRAVITY "AT A POINT" COMPARISON OF SPECIMENS CAST VERTICALLY, CAST INCLINED AT 45°, AND CAST FLATWISE.

resentative $\frac{1}{2}$ in. thick strips of steel cut from test castings risered both ways discloses very little difference with respect to the capability or superiority of one method over the other. Testifying to this fact is Radiograph 26 which shows the kind of center-line that is obtained in blind-risered specimens. The shrinkage chevrons, it will be noted, have merely been inverted and not eliminated or significantly diminished.

60. Comparing the relative feeding efficiency of open and blind steel risers, it has been found that for the same volume of metal and same favoring conditions of temperature gradient, open risers feed as effectively if not more so than blind risers. Due to the advantage of elevated position, open risers are aided in the performance of their function not only by atmospheric pressure but by gravity as well,—a force which blind risers generally must work against.

61. *Test 12:* Tapered external metal chills constitute in themselves an excellent means for directing solidification progressively toward feed heads. The sandwiching of molten metal between tapered cast iron wedges is generally productive of sound metal. Steel sections of 1 in. thickness were made solid using tapered cast iron wedges, 4 in. thick by 10 in. high, poured from a bottom-pour 10 ton ladle fitted with a two inch pouring nozzle. Rate of pour and the size of external chills required to make solid sec-

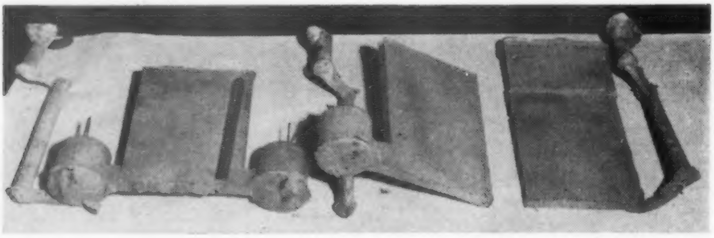


PLATE 40—GUN METAL CASTINGS VARIOUSLY RISERED.

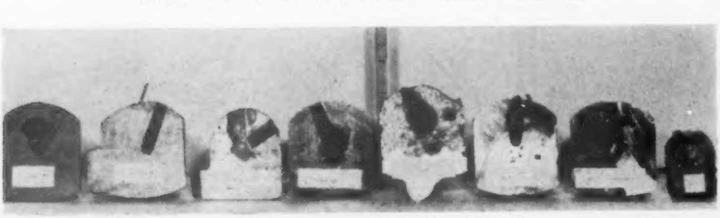


PLATE 41—BLIND RISERS CUT IN TWO.

tions are obviously related to one another. No tests were made to determine the nature of this relation. A section of such a chill-cast steel plate is radiographically featured in Radiograph 27. No visible defects are evident in the film.

62. *Test 13:* A mold whose internal cavity was maintained at 650°F. for 24 hrs.,—up to the instant of pouring—by means of electric strip heaters produced a casting containing numerous gas-chambered, lateral type defects extending from center to outside face and vice versa. Though some center-line shrinkage is apparent, for the most part the defective condition is of entirely different character. The same defect is known to occur on the cope surface in regions of extra mass: immediately under risers, heavy bosses, heavy flat padding—regions exposed to the action of extra heat. The character of the defect is shown in Radiograph 27.

63. *Test 14:* Inasmuch as different sand mixes possess different heat transference rates[9], it was believed that the differential chilling action resulting from the use of two thermally different mold materials would displace the line of central shrinkage toward the sand having the lower heat diffusivity coefficient. Accordingly, several 1 in. thick plate specimens were cast in molds faced with a 2 in. layer of green Cape Henry sand on one side and with an equal thickness of baked core sand (New Jersey silica sand) on the other. X-ray examination of the specimens discovered no detectable displacement of the center-line in either direction. Obviously, the rate of heat transference of the two sands was not sufficient to effect movement of the heat axis. If the thickness or composition of the facing layer is changed, the cooling effect also will change. According to Chvorinov[10] , such a facing need not

Table 8

MISCELLANEOUS CASTINGS TESTED FOR CENTER-LINE SHRINKAGE

Metal	*Navy Department N. D. Spec. No.*	*Grade or Class*	*Solidification Range °F.*	*Heat of Fusion Kg-c/ per kg.*	*Freezing Shrinkage per cent*
Aluminum	46A2	Gr. A	1215	86.6	6.6
Al-Si Alloy	46A1	Cl. 3	1070–1165	88.6	5.6
Copper	46C5	Gr. A	1981	41.8	3.8
Cu-Si Alloy	46B28	——	1800–1850	44.1	—
Gun Metal	46M6	——	1650–1850	38.8	—
Manganese Bronze	49B3	——	1650–1700	35.9	4.6
Ni-Cu-Si Alloy	46N7	Cl. a	2300–2400	68.0	—
CRS Steel	46S27	Gr. 1	2550–2590	48.2	—
0.25 per cent C. Steel	49S1	Cl. B	2660–2750	49.3	3.3

exceed the thickness of the cast section but should not be less than one-half of its thickness if a full cooling capacity is to be realized. The sections pictured in Radiographs 13, 14, and 14b were cast between green and core sands. No migration of the shrinkage line is evident.

64. *Test 15:* To obtain further information on the phenomenon of center-line shrinkage, other metals and alloys were tested for susceptibility to it. Radiographs 28 to 31, inclusive, show the internal shrinkage characteristics of eight different metals. Table 8 lists some of their fundamental melting properties. It will be noticed that metals with broad and narrow liquidus-solidus ranges, of few and many phases, of varied fluidity, and of high and low melting temperatures were sectioned for test. All of the specimens disclosed the presence of some center-line shrinkage. Starting with the most pronouncedly center-lined specimen, the following appears to be the order of decreasing shrinkage severity: silicon monel, B steel, CRS steel, copper, gun metal, manganese bronze, and alumnium.

SUMMARY

65. The following facts summarize the data of this and preceding tests on the fundamental habits governing center-line formation:

(a) Midwall shrinkage manifests itself most conspicuously in the ¼-, ½-, 1-, and 2-in. thick sections; faintly, in the upper half of 3-in. sections; and ever so faintly, in fact scarcely at all, in the topmost metal of 4-in. sections. In brief, the height of solid metal, as measured from the bottom upward, increases linearly with section thickness, *i.e.*, from a height of 1-in. in ½-in. thick sections to the full height of 12-in. in 4½-in. thick sections.

(b) Positioning of castings in the mold at various angles of inclination (from vertical to flat) does not increase or decrease the extent of center-line shrinkage. Position affects only the form and location of the shrinkage. The more closely a section approaches the flat lying position, the more is its shrinkage displaced in the direction of its top or cope surface.

(c) The use of sufficient feeder metal in the form of large, truncated open risers (6 in. high, weighing 80-85 per cent of the weight of the casting, and having a V/SA ratio 1½ times that of the V/SA ratio of the casting) is inadequate not only of itself, but

even with the accompanying self mold preheat, to prevent center-line shrinkage.

(d) The application of taper in increments of 1 in. per ft. to castings 1 in. thick by 12 in. high progressively decreases the amount of internal shrinkage to the point of complete elimination when taper-padded with 2½ to 3 in. of metal per ft.

(e) End and side effects as well as gravity modify padding requirements on short and high castings. The former makes its influence felt in high sections, and the latter, in short sections. The amount of padding in in. per in. increases for specimens up to 12 in. high, the increase being less for the heavy sections. And conversely, the amount of padding in in. per in. for specimens higher or longer than 12 in. decreases with height, the decrease being greater for the thinner sections. Approximately one half as much wedging in in. per in. is required for specimens 24 in. high as for the same specimens 12 in. high.

(f) A wide variety of alloys and metals is susceptible to center-lining. Each composition seems to possess a characteristic mid-wall shrinkage of its own whereby it can almost be identified.

(g) Of all the factors and influences studied, temperature gradient alone seems to be the most potent regulator of center-line formation in castings.

CONCLUSIONS AND RECOMMENDATIONS

66. The experimental evidence of this report, supplemented by several years' practical experience with padding, makes clear the fact that padding is not only a truly flexible but a most accurately controllable means of establishing positive temperature gradients in all manner and size of castings. Correctly applied, padding can be used to definite advantage by foundrymen, especially steel foundrymen. The advantage lies in the production of uniformly dense, and therefore, radiographically sound wall sections. Correct padding, coupled with good molding, is productive of steel quality of the highest order with respect to metal integrity, reliability, and physical properties.

67. A technique of padding has been worked out for the procurement of dense, integrally sound steel castings. It is recommeded that serious thought be given to its extended use by the steel casting industry to only those classes of castings in which the very highest degree of radiographic soundness is required. Of

the ten methods (listed in paragraph 15 of this paper) that may be used for making high quality castings, only two, chilling and padding, are able to produce the very high temperature gradients which are required for center-line elimination. Size and intricacy of parts make difficult the application of chilling methods. No such difficulties obstruct the use of padding.

ACKNOWLEDGMENTS

68. The authors wish to thank the following for their assistance in helping to plan and carry through the tests: H. W. Lee, ass't shop superintendent; H. H. Walkup, metallurgist; L. L. Martin, quarterman molder; and L. W. Jakeman, molder; H. L. Whitaker, junior scientific aide; all of the Norfolk Navy Yard.

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DISCUSSION

Presiding: K. V. WHEELER, American Steel Castings Co., Newark, N. J.

Co-Chairman: F. A. MELMOTH, Detroit Steel Castings Co., Detroit, Mich.

H. F. TAYLOR and E. A. ROMINSKI (*written discussion*)[1]: The authors of this timely paper have again made a fine contribution to the knowledge of gating and risering castings, one of the toughest problems the foundryman has to face.

Following a discussion of the work of Messrs. Brinson and Duma with them prior to publication, it was found that because of lack of time certain aspects of the problem were not as completely investigated as was desirable. Because of our interest and experience in the use of atmospheric pressure feeding, particularly as applied to blind risering, work was initiated at the Naval Research Laboratory to supplement the authors' efforts. The results of this investigation make it necessary to modify certain of their original conclusions. A description of the work and discussion of results follows:

Castings 1-in. thick, 10-in. wide and 12-in. high were made as shown in the sketches of Plates 42, 43, 44 and 45, two with blind heads in different positions relative to the casting and two with conventional open risers, one gated on the parting line and one step gated. The castings were then sectioned as shown in the sketches, and radiographed in the manner described by Messrs. Brinson and Duma. The first casting was made as shown in Plate 42 and half-in. thick slabs were sawed from the positions indicated. Radiograph 32* showed the section to be perfectly sound with no evidence of center-line shrinkage. The metal was also sound to deep acid and persulphate etches.

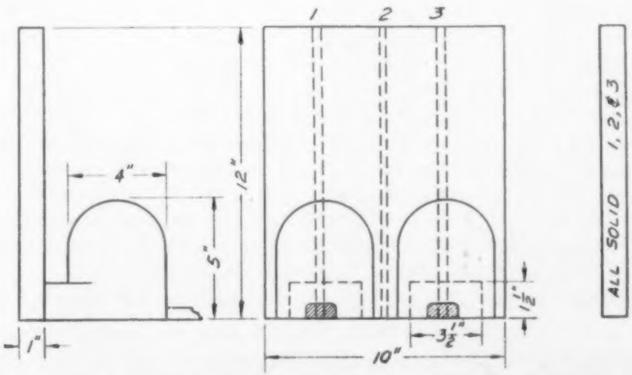


PLATE 42—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (BLIND RISER ATTACHED TO SIDE). LOCATION OF STRIPS SAWED FROM PLATE INDICATED BY BROKEN LINE.

[1] Naval Research Laboratory, Washington, D. C.

* Radiographs referred to in the discussion are reproduced on pages 759 to 765.

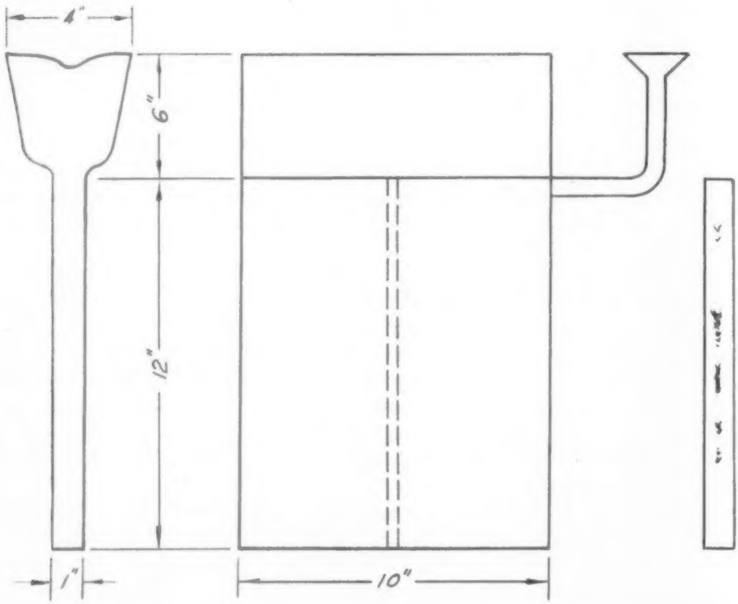


PLATE 43—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (OPEN RISER, GATED AT PARTING LINE). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

The second series of tests included each of the systems shown in Plates 42, 43, 44 and 45, and all were poured from the same heat. Radiograph 33 shows the condition of the castings. Number 1 strip was taken from the casting made with the open riser having the ingate at the parting line (Plate 43), while strips 2 and 3 were taken from the casting poured with a step gate (Plate 44). Strip 4 shows the center-line condition of the casting made with blind risers at the edge (Plate 45) the same as the ones reported upon in the text. Strip 5 shows the condition of the plate made with the blind risers attached to the flat side, after the manner of the casting made in the first test. Again this last casting was found to be perfectly sound with no evidence of shrinkage chevrons or center-line voids. The castings made with open risers or with the blind risers placed on the edge were unsound in the varying degrees shown.

From these results it is clear that the authors' statements in paragraphs 59 and 60 should be modified somewhat. It is true, as they say, that "—— given the same favoring conditions of temperature gradient, open risers feed as effectively, if not more so than blind risers." It should be pointed out, however, that this "same condition of temperature gradient" is next to impossible to attain. Because of the desirability and frequency of bottom gating the hottest metal is not usually found in

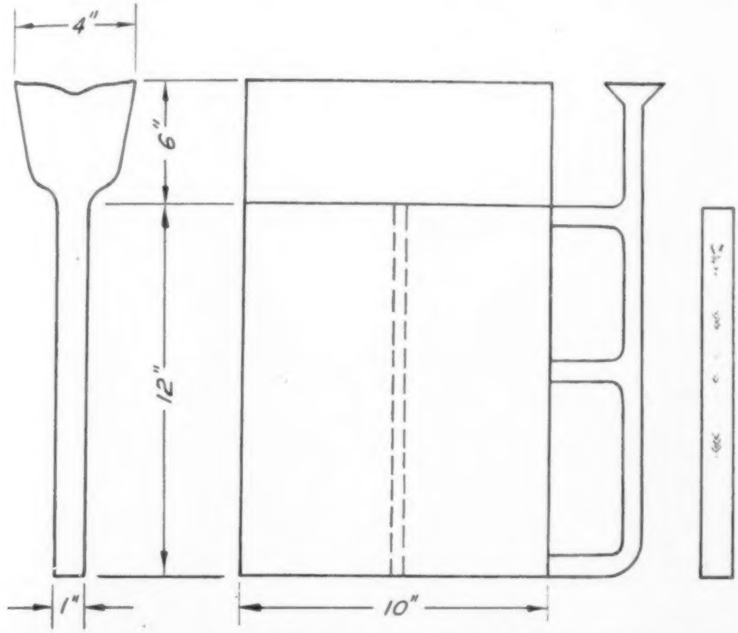


PLATE 44—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (OPEN RISER, STEP GATED). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

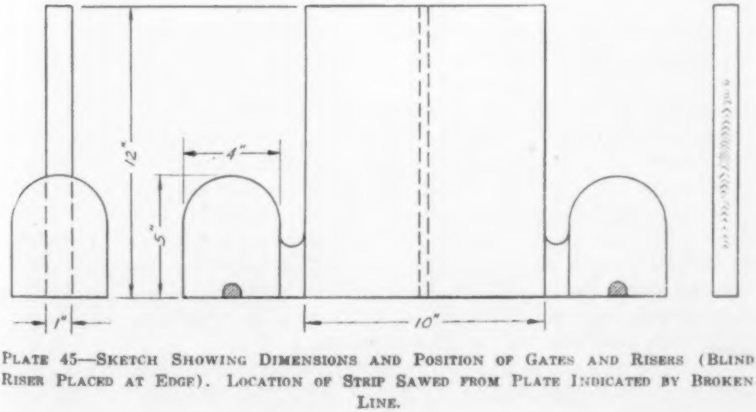


PLATE 45—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (BLIND RISER PLACED AT EDGE). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

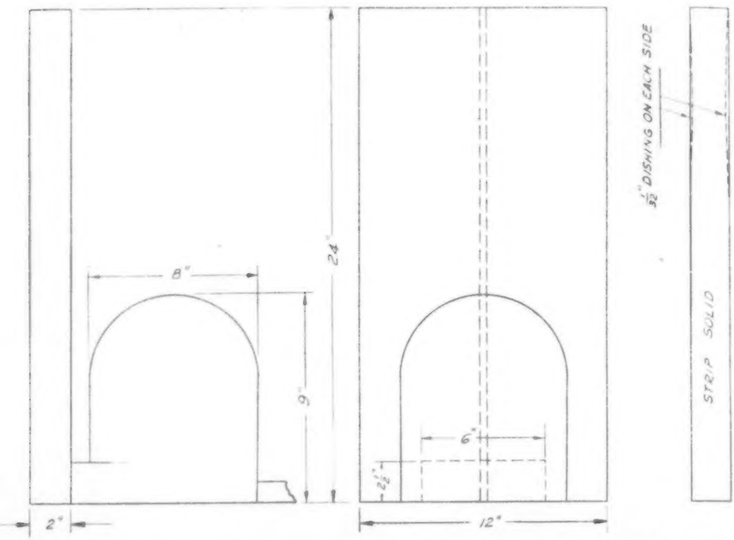


PLATE 46—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (BLIND RISER). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

the open risers where it should be, and for this reason they do not always feed well. Even if top pouring through risers or gating at the top parting line is employed hot metal is carried downward by its own inertia, preheats the walls of the mold for a considerable distance below the riser, promotes turbulence in the metal and in general interferes with the maximum control over thermal gradients and directional solidification. In bottom gating through blind risers the metal rises smoothly and evenly and proper heat gradients are established naturally. It should not be inferred from the above discussion that blind risers are always to be preferred over open types because in many cases they would not be as practical. It is safe to say, however, that for reasons discussed blind risers are really more efficient than open types and should be used whenever and wherever they are suitable. The experiments described above indicate the truth of this statement. The poor showing of the blind risers in the experiments of Messrs. Brinson and Duma was caused by the manner in which the risers were positioned and attached to the casting. Placing them at the edge and continuing the wall thickness of the plate into the blind head with a slight taper did not provide enough of a hot spot at this point and the neck froze off about as readily as the casting. Thus feeding could not take place and the castings were unsound. Placing the risers at the side, as shown in Plate 42, provides a decided hot spot at the neck and the blind head being so near the casting also disposes heat gradients in the proper manner.

Similar experiments were conducted on castings 2-in. thick, 12-in. wide and 24-in. high as indicated in Plates 46, 47 and 48. The complete de-

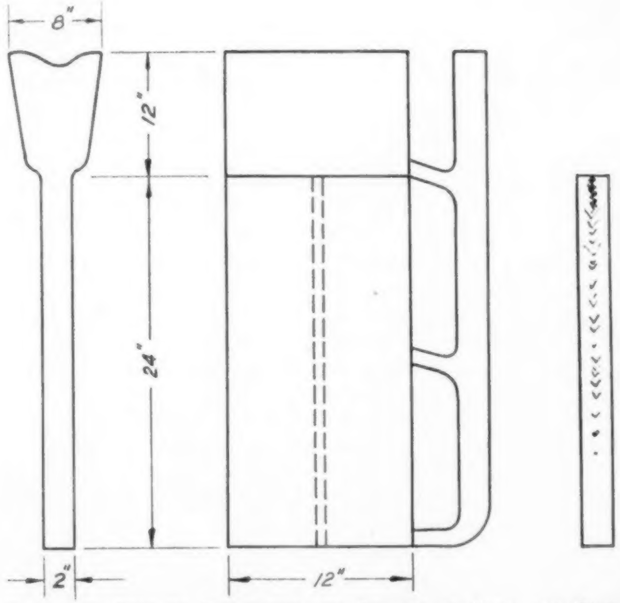


PLATE 47—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (OPEN RISER). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

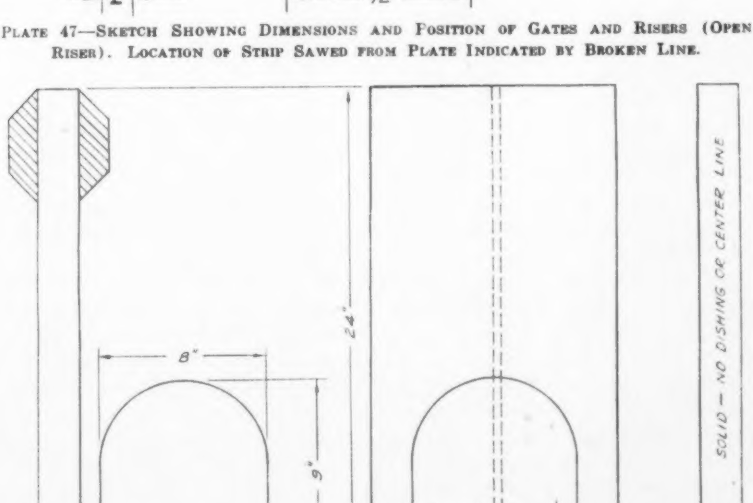


PLATE 48—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (BLIND RISER. STEEL CHILLS PLACED AT TOP OF PLATE). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

tails of the casting-riser system are given in each case. The castings of Plates 46 and 47, represented by Radiographs 34 and 35, were poured from the same heat of arc furnace steel and were repeated using individual heats of induction furnace steel. Results were identical in each case. Radiograph 34 shows the center-line condition of the casting fed with the blind riser (Plate 46) while Radiograph 35 represents the condition of the casting fed with the open riser (Plate 47). No center-line shrinkage was present in the casting fed with the blind riser while the one fed with the open riser was very bad in this respect. Step gating and gating at the top parting line produced the same order of results with the open riser. Again there is little doubt about the relative feeding efficiency of the two methods of risering. As indicated by the dotted lines at the top of the strip shown in Plate 46, there was a very slight dishing of the walls in the region shown. This amounted to less than 1/16-in. in the two-in. thickness. When steel chills were placed at the top of the casting to solidify and strengthen the walls quickly as shown in Plate 48, this did not occur and the casting was also perfectly sound internally as shown by Radiograph 36. Dishing did not occur in the one-in. thick castings nor would it occur in 2-in. thick castings a foot high. If conditions were ideal dishing would not have occurred in the 2-in. castings 2 ft. high.

The great difference in the center-line shrinkage obtained by the open and blind riser methods discussed above suggested the method of casting shown in Plate 49. Here the blind riser was placed half way up the height of the casting so that part of the plate would be fed with benefit of gravity plus atmospheric pressure and the other half with gravity actually opposing the desired direction of metal feed. Surprisingly enough the metal in the upper half of the plate (Radiograph 37-A) was perfectly sound while that in the lower half showed unsoundness (Radiograph 37-B). Shrinkage was found in the relative position shown by the shaded marks on the strip of Plate 49. This was repeated three times with the same results, leaving only the conclusion that conditions of metal flow were responsible for the widely divergent results. It was at first quite odd that metal should feed upward against gravity when it would not feed downward from the same riser, but, after due consideration, the results were logical enough. During the filling of the mold cavity the metal entering through the riser neck into the casting washed downward into the lower half of the mold with considerable force even when the metal had risen nearly to the level of the ingate. This caused turbulence in the metal and, also, probably preheated the mold walls to a fairly constant temperature for some distance below the riser. Thermal gradients were disturbed and the coldest metal of the bottom half of the casting was not necessarily progressively farthest from the riser. Bridging dendrites kept the feed metal from getting through. The metal in the upper half rose steadily with no turbulence during filling of the mold and the proper heat gradients were readily established. Only by this manner of reasoning can the seeming anomaly be explained.

A relatively few tests made at this Laboratory indicate that the analysis, and particularly the state of deoxidation of the steel also in-

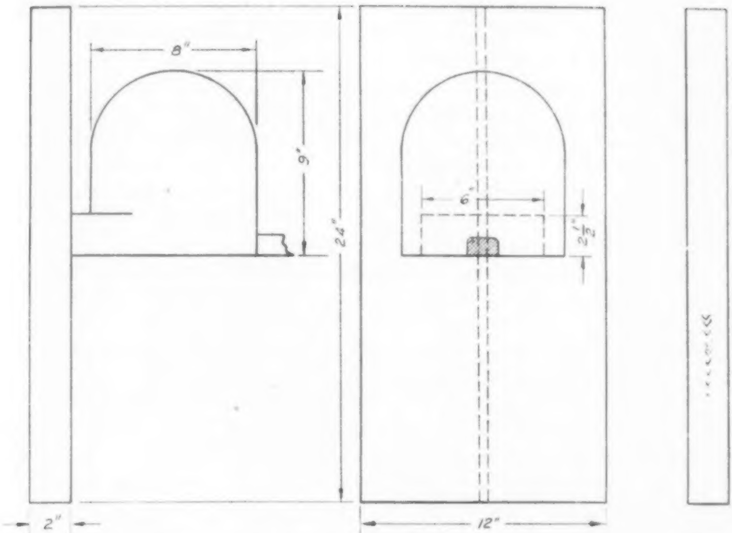


PLATE 49—SKETCH SHOWING DIMENSIONS AND POSITION OF GATES AND RISERS (BLIND RISER PLACED HALF-WAY UP THE HEIGHT OF CASTING SO PART OF PLATE WAS FED WITH BENEFIT OF GRAVITY PLUS ATMOSPHERIC PRESSURE AND THE OTHER HALF WITH GRAVITY OPPOSING DESIRED DIRECTION OF METAL FEED). LOCATION OF STRIP SAWED FROM PLATE INDICATED BY BROKEN LINE.

fluence center-line shrinkage and for a given method of risering the extent of the defect is variable. Also it seems that pouring temperature should have some effect by the influence it would exert upon temperature gradients.

The authors have very clearly shown what happens in a good many castings and why it is essential that particular care be taken in the making of pressure units and have further clarified the use of padding in the attainment of proper heat gradients. It is to be hoped that many investigators will follow their lead with similar researches to the end that the soundest possible casting can ultimately be made in the most economical manner. The curvilinear type of padding shown in 1f of Plate 6 merits considerable attention since from the authors' results it is fully as efficient as the straight line taper and effects more than a threefold saving in weight.

J. B. CAINE (*written discussion*)[2]. Messrs. Brinson and Duma are to be congratulated on their paper. They not only have made a complete report on the phenomena of center-line shrinkage, but, what is equally important, have given quantitative data on what to do to eliminate it.

Unfortunately, the method of eliminating this center-line shrinkage is very expensive. If we are to use the padding recommended on one-in.

[2] Sawbrook Steel Castings Co., Lockland, O.

sections, the amount of metal needed to pour the section is increased 250 per cent, and the cost of the additional metal is only a small part of the cost of removing it afterwards.

The use of padding to eliminate center-line shrinkage on castings that are to handle gases and liquids at high pressure cannot be questioned. However, in the case of structural castings that constitute the bulk of the steel castings produced, it is still questionable that the physical properties of the castings as a whole are impaired by the type of defect discussed in this paper. The authors have mentioned this fact in paragraph 15, but have not gone into detail.

In paragraph 55 the authors state that the strength and ductility values in tension have been decreased by the center-line shrinkage in unpadded sections by 20 and 50 per cent respectively. It is true that the tensile strength has been reduced, but the yield point, the property that is much more significant in design, has been reduced very little. As can be seen from Table 7, the test bars, with the lowest yield point in the 1-in. unpadded section, only average 2,000 lb. per sq. in. lower than the corresponding bars in the section with 3-in. per ft. padding. The actual increase in the design strength due to padding is then less than 5 per cent.

The elongation and reduction of area in tension have been lowered greatly. However, it is recognized by leading authorities* that these values are of little or no value in themselves, and their only justification is that they are supposed to be related to the ability of the metal to withstand shock. Even this last point does not check with the experimental evidence**.

The authors have shown in Table 7 that the much more important property, notch sensitivity, or the resistance of the metal to failure under dynamic loading due to stress concentration, is lowered by center-line shrinkage in unpadded uniform sections. It is interesting to note that the decrease in this property is much less than that of elongation and reduction of area in the tension test.

However, if we consider the casting as a whole, we have an entirely different picture of its resistance to stress concentration than that shown by the specimens taken from the center of the section as done by the authors. First, except in the unusual case of axial loading, the maximum stress is at the surface, the stress decreasing to zero somewhere in the center of the section. As is shown in this report, the Izod values of this surface metal as well as the density are high regardless of whether the section is padded or not. With normal amounts of finish, this area of high density is not all removed. Secondly, concentrations of stress are very seldom located in a uniform section, but are present at junctions of sections. At these junctions the laws of center-line shrinkage no longer hold.

There are at least two exceptions to the above statements: One, if deep grooves are machined into the section, and, two, if the section is cast

* SYMPOSIUM ON SIGNIFICANCE OF THE TENSION TEST OF METALS IN RELATION TO DESIGN, American Society for Testing Materials, 1940.

** SYMPOSIUM ON IMPACT TESTING, American Society for Testing Materials, 1938.

horizontally, displacing the center-line shrinkage into the outer metal on the cope surface. Even these two exceptions can usually be taken care of without the use of extensive padding. Just the areas where the deep grooves are machined can be well fed by padding or closely spaced risers. The whole casting need not be padded. Critical sections can be so positioned in the mold that they are either vertical, throwing the center-line shrinkage into the center of the section, or if they must be cast horizontal, keeping the displaced shrinkage in the compression side of the casting.

The same factors apply equally well to the other important property of design strength, resistance to fatigue. This is again a question of stress concentration, not so-called ductility. One point should be emphasized regarding fatigue. The radiographs of center-line shrinkage make the shrinkage areas appear to be discrete cracks in the metal, whereas they are not. In reality they are areas of metal of lower density than the surrounding metal and do not cause near the stress concentration that a discrete crack would create.

MEMBER: I would like to know the height of the straight run in Plate 6.

MR. DUMA: The dimensions of the casting are: 10-in. wide, 12-in. high and one-in. thick. It is tapered from the bottom to a height of half-way with a taper of one-in. per ft. From this half-way point to the top it is padded with a 6-in. radius drawn to a 4-in. width at the top.

MEMBER: To what extent, if any, would center-line shrinkage be affected by gating? Since center-line shrinkage is the result of the steel coming in contact with the mold surface and cooling from the outside towards the center, to what extent would a section be affected by gating? What is the location of the ingates into the cavity of the mold?

MR. DUMA: All specimens were top-gated and the metal top-poured to obtain a favorable temperature gradient because they were risered on top. We also tried gating at the bottom in padded and unpadded sections. In the unpadded sections the center-line shrinkage was very pronounced, but the "V's" were inverted, *i.e.*, they pointed slightly downward. In the padded sections, it takes a slightly greater amount of padding or wedging to overcome the adverse temperature gradient obtained by bottom gating. We found the sections had to have 2½-in. to 3-in. of padding to have no center-line shrinkage, 2½-in. if top-poured, and 3-in. if the metal was introduced through the bottom gate.

MR. BRINSON: It is just a question of correlating the position of the gate with the riser to try and put the gate in the most advantageous position.

MEMBER: Would center-line shrinkage be greatly overcome by promoting direct solidification?

MR. BRINSON: Padding would help it.

MEMBER: What does the rate of filling the mold have to do with center-line shrinkage? I know that if the mold is poured with hot metal very slowly, less padding is necessary than if it is poured fast.

MR. BRINSON: The only reason we could give for the center line seem-

ing to disappear in the 4-in. sections is that it takes longer to fill up the mold, giving the effect of slow pouring and more temperature gradient.

MR. DUMA: The upper and riser areas of molds are preheated by radiated heat issuing from inflowing metal and from gradually rising metal. The slower the rate of pouring, the more pronounced is the consequent preheating of the molds, and, therefore, the steeper the final temperature gradient. Whatever helps to set up a steeper temperature gradient will also aid in reducing the amount of padding required.

CO-CHAIRMAN MELMOTH: There is a definite parallel of the subject of this paper with ingot practice, where controlled taper is used to eliminate center-line effects. I have said many times that the foundryman's insistence on uniform metal would turn out to be to his decided disadvantage. We do not really wish for uniformity of section, but rather for controlled variation of section in order to produce progressive solidification with soundness. Speed of pouring in some conditions can exert quite an influence on the degree to which this defect occurs. In ingot practice this is realized, so much so that in many cases of an important type, pouring speed is under definite and standardized control.

The information in the paper is extremely valuable to the designer of parts to be made as castings. If the designer could be sold on these demonstrated facts, and the information so put to practical use, we would have less need to resort to padding, and its inevitably costly removal. Such designing would open up entirely new vistas of the possibilities of casting utilization.

I do not believe that center-line shrinkage, at any rate in significant degree, exists in all castings. Were it so, and assuming it to be present in the degree shown, I believe service failure would by now have almost eliminated the steel casting as an engineering material. I feel that there are factors effective in actual castings which cannot be evaluated by means of experimental sections, independently poured. Most founders of any experience have cut up hundreds of castings, and would have little or no confidence in the integrity of their product if center-line shrinkage in the degree shown had been experienced.

We do not doubt but that steel castings can bear improvement. But, based on service failures, we believe their integrity is much higher than would be conveyed by the results shown in the authors' separately cast uniform sections.

MR. BRINSON: I agree that it is a paper for the designer as well as for the foundry. Last year a paper was presented on the use of models in connection with making steel castings and the same remarks were made about the design then. At our plant we took the model of a turbine casting as made according to the drawing and added a taper on that casting, by means of model wax, to get controlled directional solidification. That was incorporated in the design. I do not believe in taking one lb. or 20 lb. off of the casting if it can be designed so that it is not necessary.

We did not have any idea of presenting this paper to reflect on the integrity of the steel casting industry. We made no statement as to

what way or how much this center-line weakness may affect the casting. Perhaps in a great number of cases the casting will be just as good and last just as long with it as without it. A high pressure steam valve that had been in high pressure service for a period of 12 years was brought to us to be repaired, and we radiographed it. After we radiographed it, we had to make another one. We sectioned the old one and took photographs of it. There is not a man with a boy in the Navy who would want him to be in the engine room of a destroyer with that casting at 275 lbs. pressure if he knew its condition, yet it had been in service for 12 years and had given no trouble. Some parts of the wall thickness were only 25 per cent effective.

We are not trying to reach the ultimate and make an absolutely perfect casting. What we are trying to show is what has to be done by molding methods, design, etc. We want to get rid of these things as much as we can, so the integrity of steel castings will go still higher and not lower. We all know a short while ago the steel casting industry integrity was not so very low. However, I know, as far as the Navy Department was concerned, it was not so very high, either. That is the idea we are trying to put over, not the idea that steel castings are no good. We firmly believe in steel castings—we are 100 per cent sold on steel castings—but we are trying to show what we are up against in regard to radiograph inspection of castings for the Navy.

F. J. SEDLAK[3]: Do you propose to carry on this investigation on metals other than steel, for instance, on a single component metal-like pure copper or on some of the brasses and bronzes?

MR. BRINSON: We have done a little work on that, but we have not gone very far. We do not think it is so necessary because cast iron and bronzes are not used for high pressure work and, therefore, we do not consider center-line weakness as important as it is in the steel casting.

MR. SEDLAK: In sections considerably less than ½-in. thick, I have noticed the same thing, perhaps not exactly a shrinkage, but a coring effect.

G. DOAN[4]: Does not Mr. Brinson's example of a pressure casting with 12 years of service, in spite of 75 per cent defects in the wall, prove something? To me it signifies that really sound castings can be reduced in weight to a fraction of what they now weigh. That such castings will command a higher price per lb. and will enter fields where they now cannot compete seems obvious.

MR. BRINSON: That probably naturally follows from the results that have been secured. If too thin a section is made, people will lose confidence in it, and that lack of confidence makes them fearful of the job.

C. E. SIMS[5]: I like Mr. Brinson's story of cooperating with the inevitable. Center-line shrinkage in parallel wall castings is inevitable if the castings are big enough. That is because the solidification is from the surface to the center and the whole center-line solidifies about the same time. On the other hand, in a tapered casting, such as one with

[3] Ohio Brass Co., Mansfield, O.
[4] Lehigh University, Bethlehem, Pa.
[5] Battelle Memorial Institute, Columbus, O.

a pad, the top part of the casting acts as a riser or feeder for the lower part and the center-line solidifies from the bottom to the top.

In the matter of center-line shrinkage or weakness, let us think of it first as shrinkage. I think center-line shrinkage is one of the most serious factors in giving leaky castings, especially when they are machined. In the matter of strength I think there is an entirely different story. In a section one-in. thick by one-ft. high, it will get perfectly solid and the center-line shrinkage can be eliminated by padding it to a thickness of 3-in. at the top. A casting 6-ft. high and one-in. thick at the bottom would have to be 18-in. thick at the top to get it sound to the center which is, of course, impracticable.

Mr. Melmoth's discussion shows the correlation between padding and ingot practice. He mentioned that in some sections with parallel walls, there is probably no center-line shrinkage. I think it is present to some extent in all parallel wall castings. It is impossible to prevent this center-line shrinkage in some castings, and there are millions of castings in service today that have center-line shrinkage.

As far as strength is concerned, tubes have very high strength for their weight because of their structure. The same amount of metal that is in a tube made into a solid rod will have very much less structural strength because it will not be as rigid.

Castings which are not machined, in many uses, are loaded as a beam. One surface will be in compression and the other surface will be in tension, while the center-line which is the neutral axis, will not be stressed at all. The casting, under those conditions, is virtually unweakened by the presence of center-line shrinkage.

The most severe service that I can think of, offhand, seems to run to the railroad side frame casting which is cast in about ⅝-in. sections throughout. It has to be so designed as to stand a static load of about 500,000 lb., and it is put into terrifically dynamic service, bouncing over rail joints and around curves, under the high speed of present-day freight traffic. These castings have a splendid record for service and stand up over the years, with very few breakages, until they become obsolete in design, but every one of those castings has center-line shrinkage in much of the section. Let us think of center-line shrinkage in terms of the type of casting and, wherever it is possible, as in the smaller castings, let us eliminate it by using this sound principle of getting directional solidification by tapering the casting. But let us not unqualifiedly condemn a casting because it has center-line shrinkage.

MESSRS. DUMA AND BRINSON (*authors' closure*): Due to the lack of time the authors were unable to comment on the verbal discussion of C. E. Sims. We fully agree with Mr. Sims that center-line weakness in parallel wall castings is inevitable if this parallelism extends to any great extent. Fortunately in many castings this condition does not exist, as there are many closely adjacent heavy sections, so that the problem to overcome becomes hot tearing, rather than center-line weakness.

The example given by Mr. Sims, that a 6-ft. casting one-in. thick would have to be made 18-in. thick at the top, does not follow from the results

given in our paper wherein we showed that a parallel wall casting 4-in. thick would be solid for at least 12-in. and maybe more, due perhaps to the temperature gradient set up by a longer pouring time. This condition would apply to a 6-ft. casting and the padding could at least be added in parallel steps.

In regard to the question raised as to what extent center-line weakness would affect the use of the casting (the same question raised by Mr. Caine in his written discussion), the authors with their 12 years' experience in radiographing and examining castings which had been in severe service, often at high pressures, would be the last to say that center-line weakness would to any great extent affect the use of the vast majority of castings. They wish, however, to call attention to the fact that due to the irregularity of the center-line shrinkage cavity, under certain conditions of stress (because even if the shrinkage occupies the neutral axis, there is compression on one side of the center-line and tension on the other side), cracks may be started. For example, in the case of a valve casting under pressure, if there is a marked center-line cleavage the casting becomes two separate members, each of which are under compression on the side nearest the center of the valve and in tension on the side furthest away. Any crack, therefore, developing in a valve should travel toward the center of the casting.

In regard to the point raised by Mr. Caine as to the expense, any customer who sets high radiographic standards in a casting should be willing to pay for obtaining them, because if these standards are to be met, certain procedures will have to be followed to meet them regardless of expense. Our motto is, "There is nothing as expensive as a rejected casting." This may not always be so in dollars and cents, but it is always true in the value of confidence in the integrity of steel castings.

The authors also appreciate the written discussion of Messrs. Taylor and Rominski who had an advantage over other members of the Association in that they saw certain results prior to the submitting of the manuscript. We all know that the last place to solidify in a casting is the hottest place, and that our aim is to make this place the riser, regardless of how obtained, as different casting conditions govern different methods.

The authors, as well as all foundrymen, realize that the bottom pouring of a casting, with an open or any other kind of riser on top, is just the reverse of the best condition, and the history of steel founding is replete with records of different ways to avert this condition, such as step pouring, back pouring in risers, reversing the mold, etc. However, we cannot agree with the statement made by Messrs. Taylor and Rominski that, "Even if top pouring through risers or gating at the top parting line is employed, hot metal is carried down by its own inertia, preheats the walls of the mold for a considerable distance below the riser, promotes turbulence in the metal and in general interferes with the maximum control over thermal gradients and directional solidification. In bottom gating through blind risers the metal rises smoothly and evenly, and proper heat gradients are established naturally." This is a

very easy theoretical explanation, but, unfortunately, does not agree with natural laws or practical founding. The main success of the bottom poured blind risers lies in the fact that all of the metal in the casting passes through the blind riser chamber making this hotter than any other place. Similarly, metal being passed between the mold walls from the top to the bottom and the metal rising in the mold will establish a temperature gradient in the molding media from the bottom to the top. Every foundryman who has experienced the burning down of the cope will verify this fact. We do not believe, however, that this heat gradient in the mold walls is sufficient of itself to cause the proper directional solidification. It is to be assumed from the statement, "In bottom gating through blind risers the metal rises smoothly and evenly and the proper heat gradients are established naturally," that the theory is that the metal entering the bottom of a mold through a blind riser is pushed up in successive layers, the same as a piston is pushed up in a cylinder, so that the coldest layer (the first metal in the mold) will be at the top and so on down to the hottest at the bottom. The authors have many times watched metal rising in the mold from a bottom gate and have seen the rolling action of the metal due to the hotter lower metal pushing up in the center, rolling the colder outer metal up against the side of the mold. The authors, in pouring a large steel mold, many times have waited a few minutes and then started to back fill by pouring in the risers, only to see the hot metal poured in one riser travel through the casting (where not desired) and come up in several other risers, 3 to 6 ft. distant, sometimes rolling out around the rim of the formed skin. The dishing in at the top of the casting shown on Plate 46 proves that the casting had a hot spot and tried to overcome the vacuum created by breaking through at this point. The placing of chills as shown in Plate 48 overcame this, however, and set up a proper thermal gradient down to the riser. Turbulence is a word generally used, as it is here, to describe an undesirable condition, but no practical foundryman ever objects to turbulence in pouring a casting unless it results in cutting the walls of the mold. Turbulence, properly controlled, is often an asset. The best way to obtain a clean, plain, hollow, cylindrical casting, especially with iron or bronze, is to top pour through drop gates to purposely create turbulence on the top of the rising metal. This keeps the top skin broken up and keeps any entrapped dirt on top of the metal.

The authors quite fully agree that the attaching of the blind riser on the flat side of the plate is more satisfactory than attaching same to the edge of the plate. This brings up the old question of the efficiency of different shaped risers. The authors have always contended that location, as well as shape, determine the feeding efficiency of risers. A riser which is so shaped and so located that it gets the feed metal to the point needed, by the quickest and shortest route, will feed a casting more effectively than a riser remotely situated but having the least amount of surface for the greatest volume of metal, thereby giving a slightly higher thermal efficiency in the riser itself. With the blind riser attached to the edge of the plate, the neck, no matter how much thicker it is than the casting, can only be as efficient as the thickness of the

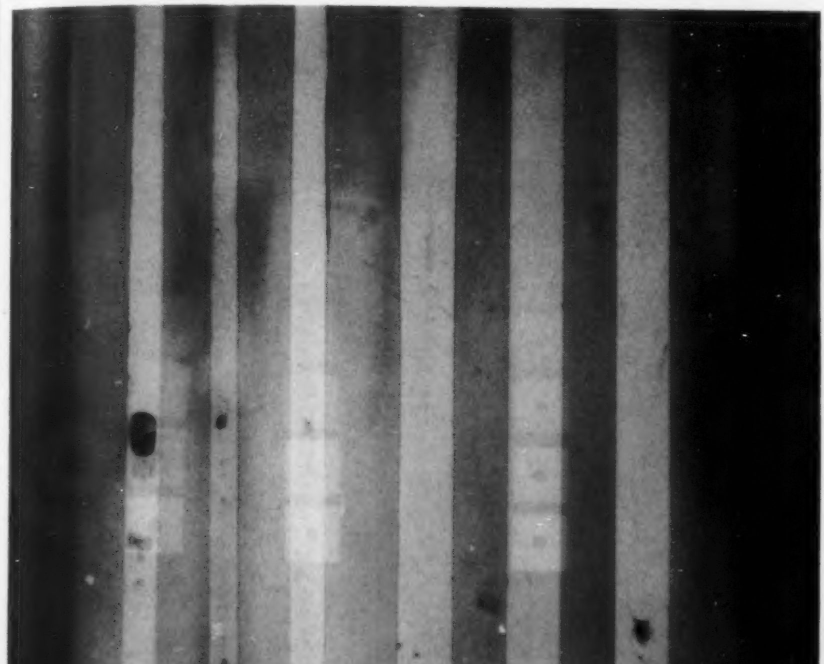
casting itself, especially so where this part of the casting has to feed the other parts.

The findings of Messrs. Taylor and Rominski parallel and corroborate those of the authors. The principal points of difference are in the interpretation and explanation of the results, and that always allows room for argument. The explanation of the results obtained on Plate 49 is at variance with actual facts. It is noted that the bottom of the ingate to the casting is located about midway and that this ingate has a section 6-in. x 2½-in. by a length of about one-in. The section of the ingate to the blind risers appears to be about 1-in. x 1½-in. It is evident that in pouring this casting the metal, in reaching the blind riser, will spread out in a thin layer 6-in. wide and not as high as the riser ingate. This metal will lose its velocity and should almost gently roll over the edge where the ingate joins the casting.

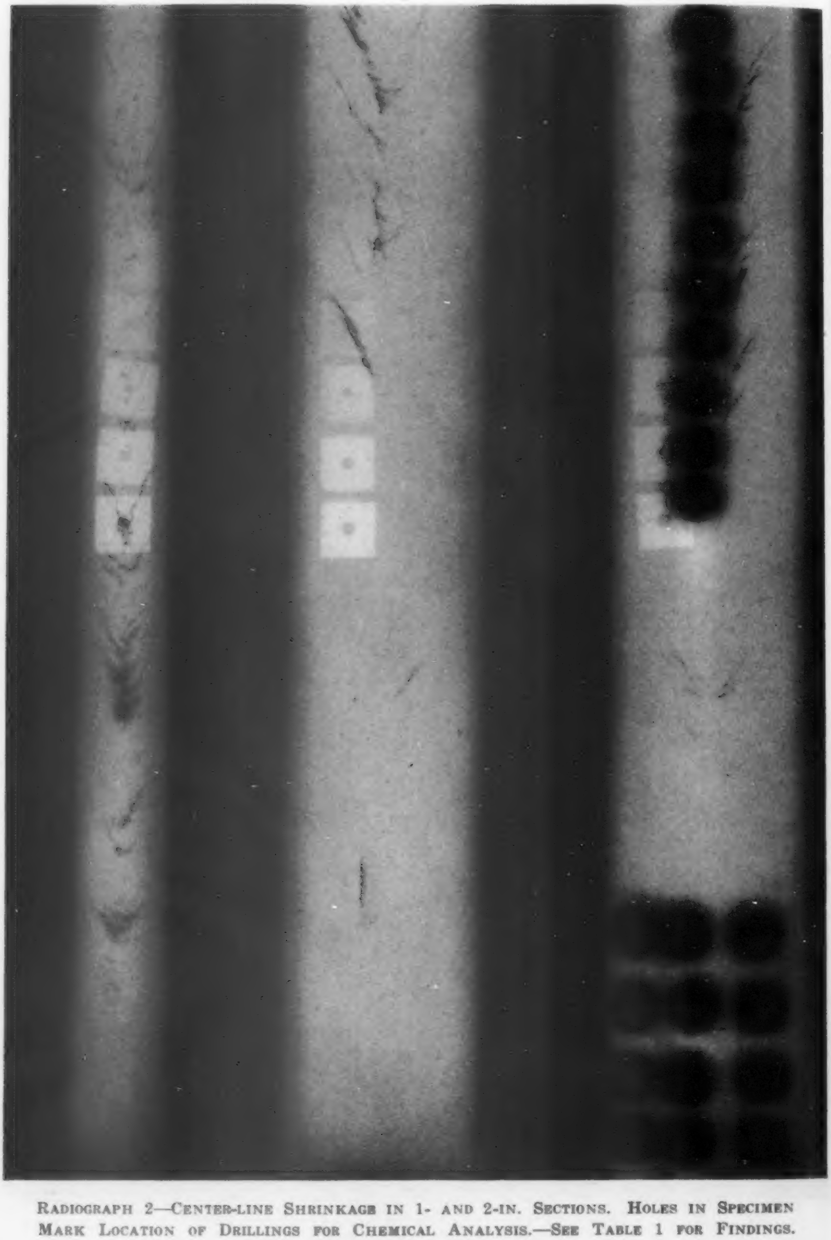
The 240 cu. in. below the ingate fills rapidly without establishing any marked thermal gradient, and the blind riser chamber is not appreciably heated up, so that in filling the bottom half of the mold, practically the same conditions are present as if it were an open top risered job with the gate at the joint of the casting and the riser. From this point on, the conditions change. The upper half of the mold (above the bottom of the ingate to the castings) contains a total of approximately 650 cu. in. or 2.7 times the volume of the lower half, and as the mold and the blind risers are filled simultaneously, then it will take at least 2.7 times longer to fill the upper half. This, coupled with the fact that the blind riser cavity is filled and heated to a much higher temperature, establishes a much better thermal gradient than can possibly be established in the lower half.

We cannot agree with the statement of Messrs. Taylor and Rominski that the analysis and particularly the state of deoxidation of the steel also influence center-line shrinkage to any extent that is worth considering. We have always contended that center-line weakness is a physical characteristic of the solidification of any metal, be it steel, iron, monel, brass, bronze, or aluminum. The statement by Messrs. Taylor and Rominski that, "Also it seems that pouring temperature should have some effect by the influence it would exert upon temperature gradient," is ambiguous as they do not say whether it should be higher or lower. We, however, fully agree with the statement as made, if not as intended. We believe that hot pouring accentuates the center-line condition. There is no center-line weakness until after solidification, and as all medium carbon steels start solidifying at somewhat the same temperature, if the casting is poured on the hot side, there will be a wider time gap between the finish of the pouring and the start of solidification and this will have a tendency to level the temperature gradient established in pouring. On the other hand, if metal could be poured cold enough to establish such a wide temperature gradient that it would progressively solidify as fast as it was poured, there would be no center-line shrinkage or weakness and there would be no need for a riser of any kind to obtain a solid casting.

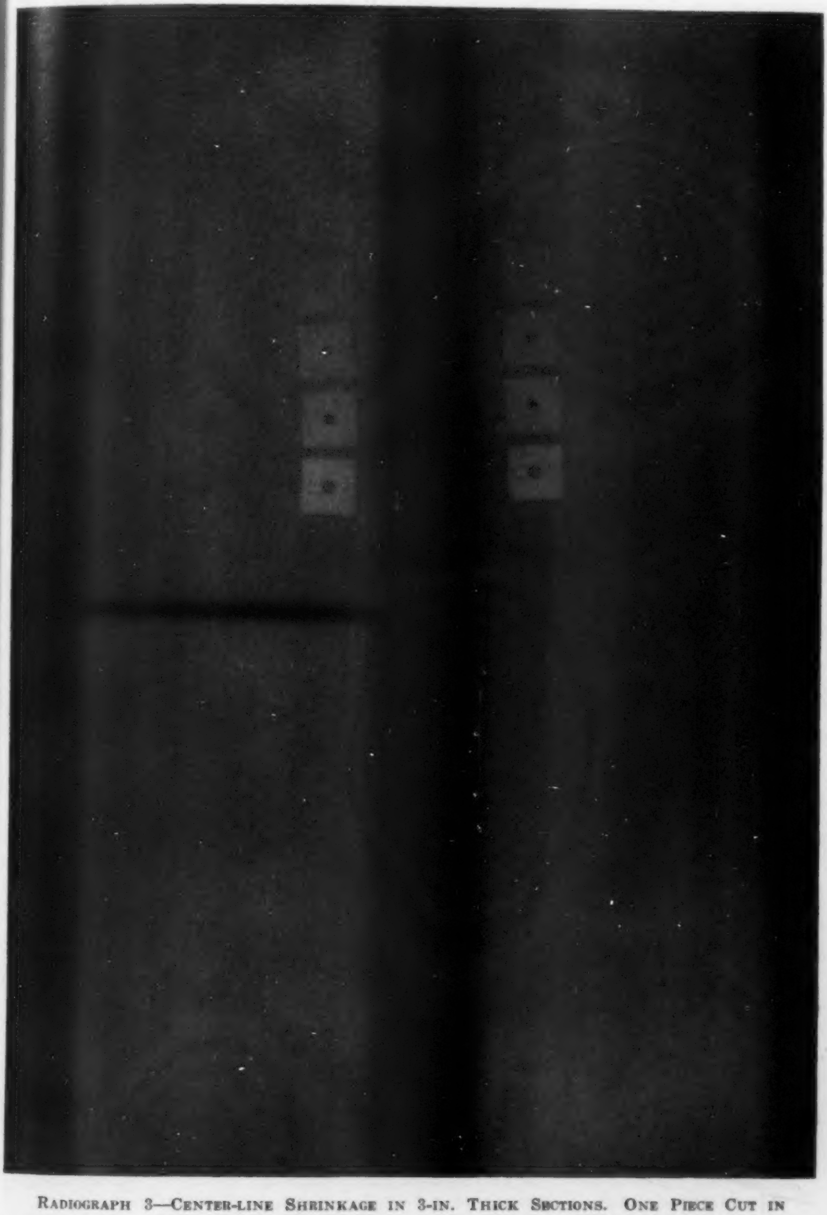
The authors recognize the results obtained by Messrs. Taylor and Rominski, but question their explanations. We feel that the whole question is simply one of establishing a proper thermal gradient in the casting, regardless of the manner in which it is accomplished, as different conditions will require different applications. The authors had hoped to conduct further experiments concerning the discussion submitted, both verbal and written, but have found it impossible to proceed further at this time. The authors wish to thank all of those who took part in the discussion, in any way, to bring out the different features, as the value of any paper can be judged mainly by the discussion it brings forth.



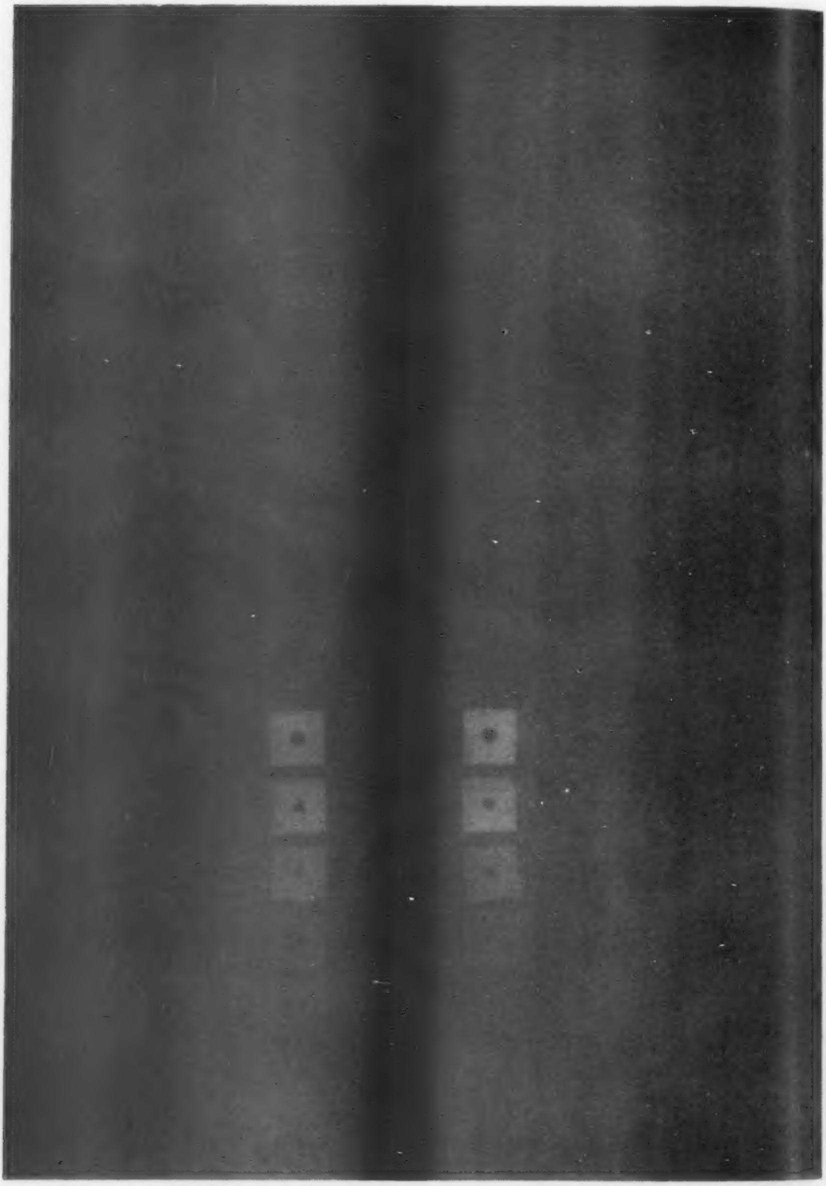
RADIOGRAPH 1—CENTER-LINE SHRINKAGE IN ¼- AND ½-IN. THICK SECTIONS—PIECES IMMERSED IN FINE COPPER SHOT. (FIGS. 2A, 3B—PLATE 4)



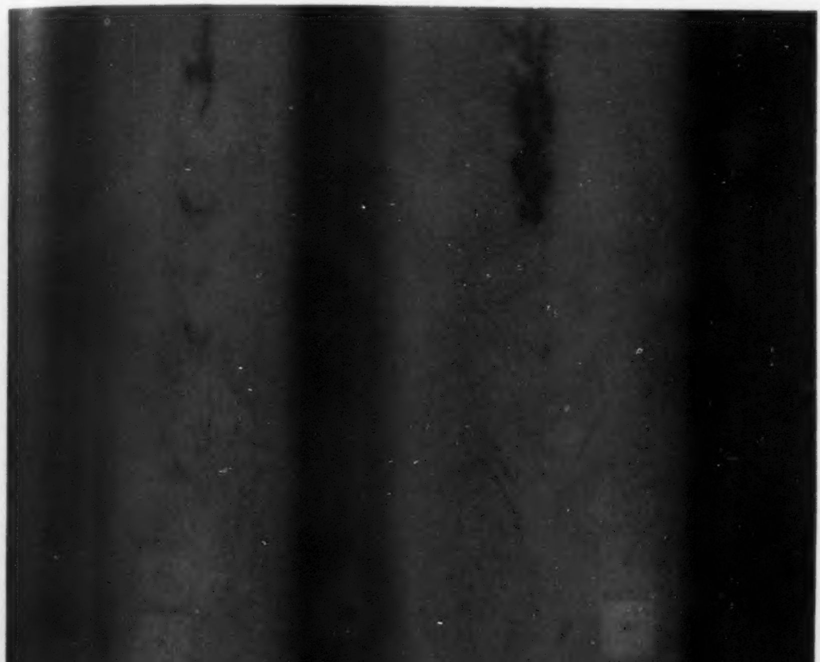
RADIOGRAPH 2—CENTER-LINE SHRINKAGE IN 1- AND 2-IN. SECTIONS. HOLES IN SPECIMEN MARK LOCATION OF DRILLINGS FOR CHEMICAL ANALYSIS.—SEE TABLE 1 FOR FINDINGS. (FIG. 1A, PLATE 6; FIG. 2C, PLATE 4)



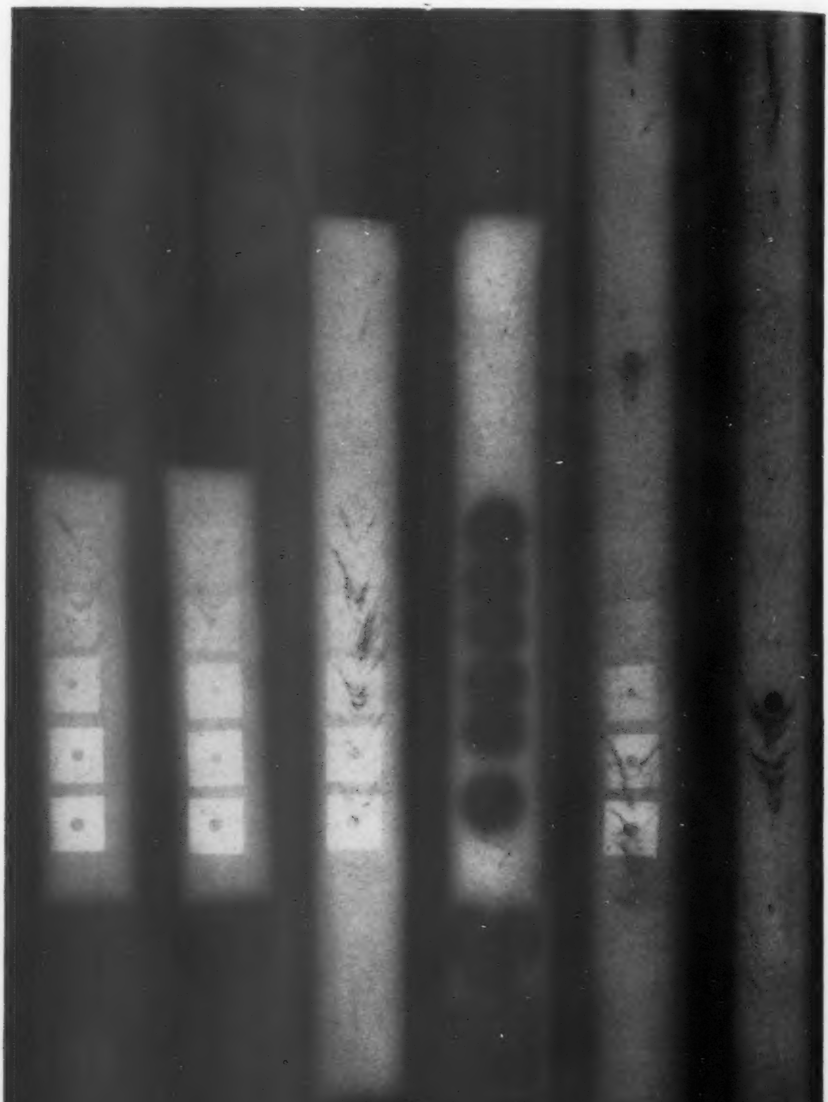
RADIOGRAPH 3—CENTER-LINE SHRINKAGE IN 3-IN. THICK SECTIONS. ONE PIECE CUT IN TWO FOR MICROSCOPIC EXAMINATION. (FIG. 2D., PLATE 4)



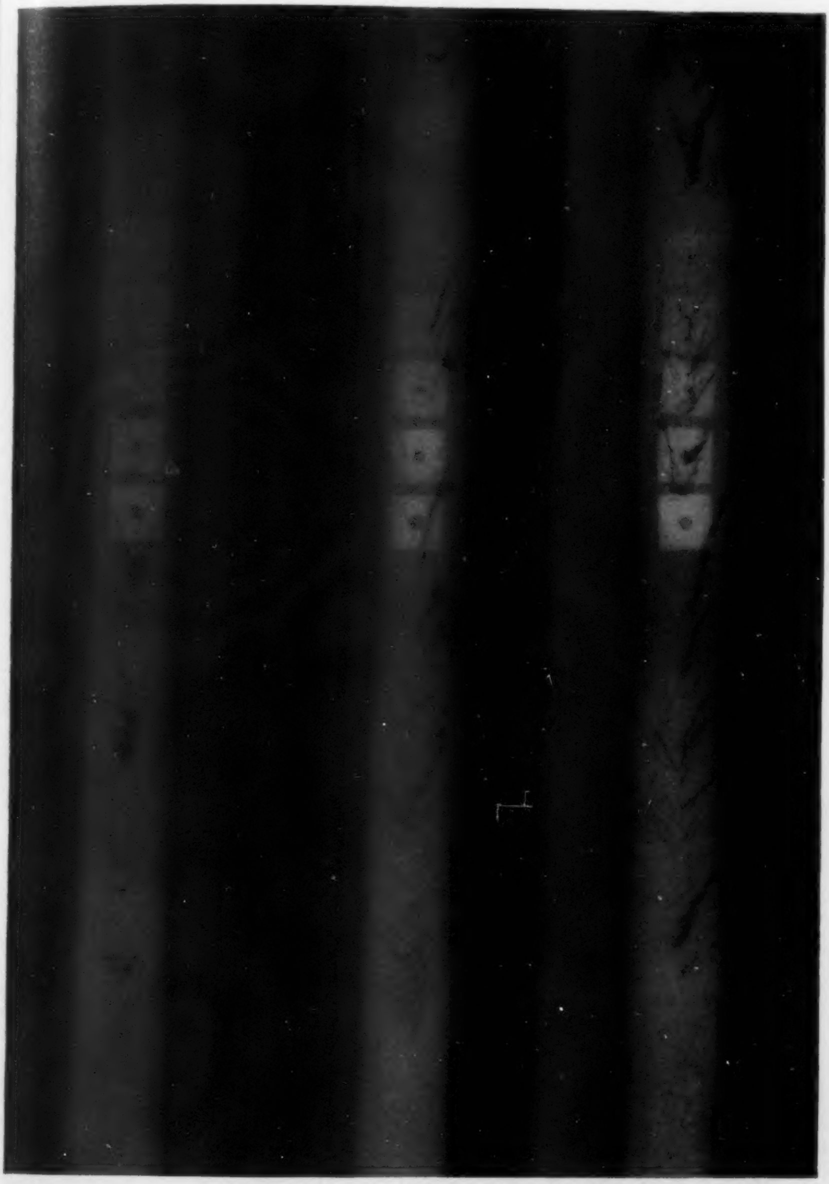
RADIOGRAPH 4—CONDITION OF METAL IN 4-IN. THICK SECTIONS.—NOTE PRESENCE OF FINE SHRINKAGE IN TOP METAL. (FIG. 2C, PLATE 4)



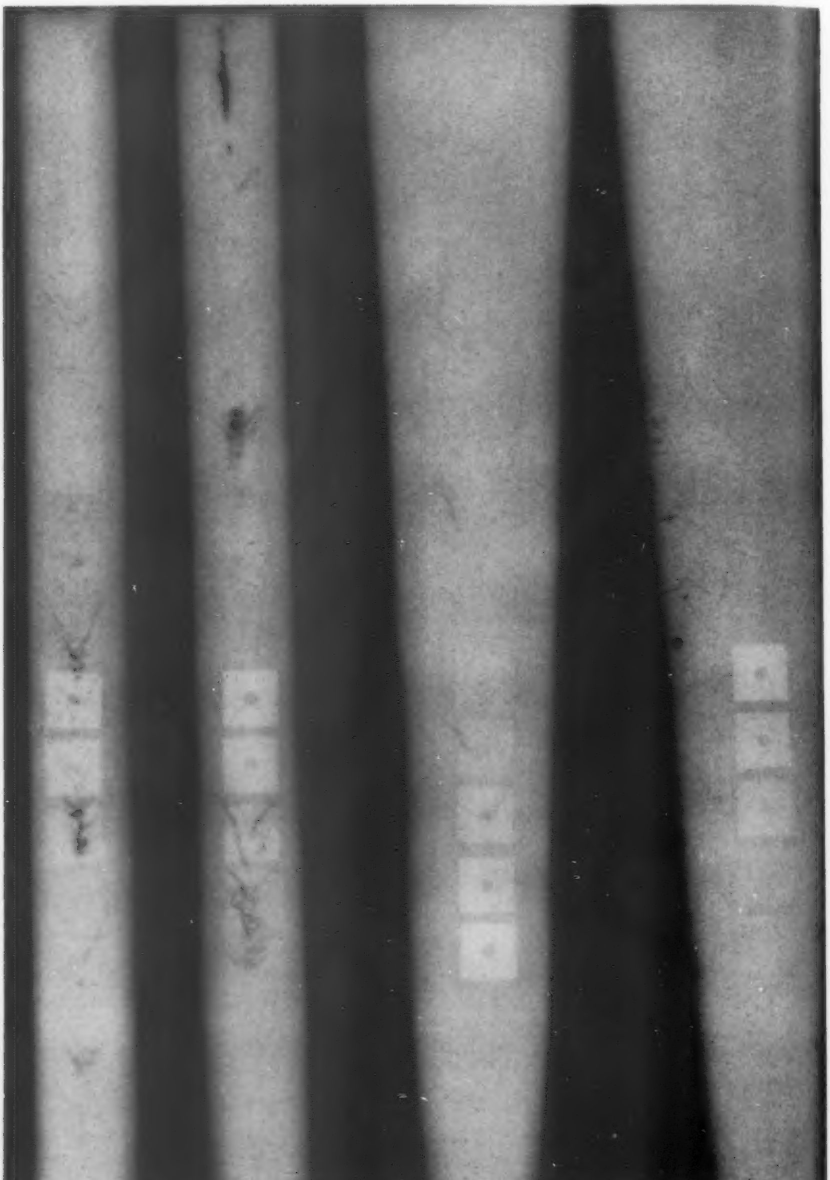
RADIOGRAPH 5—CENTER-LINE SHRINKAGE IN 2- AND 3-IN. ROUND CAST BILLETS—SPECIMENS ARE ½ IN. THICK CUT ON THE DIAMETER AND THE VERTICAL AXIS OF THE CYLINDER.



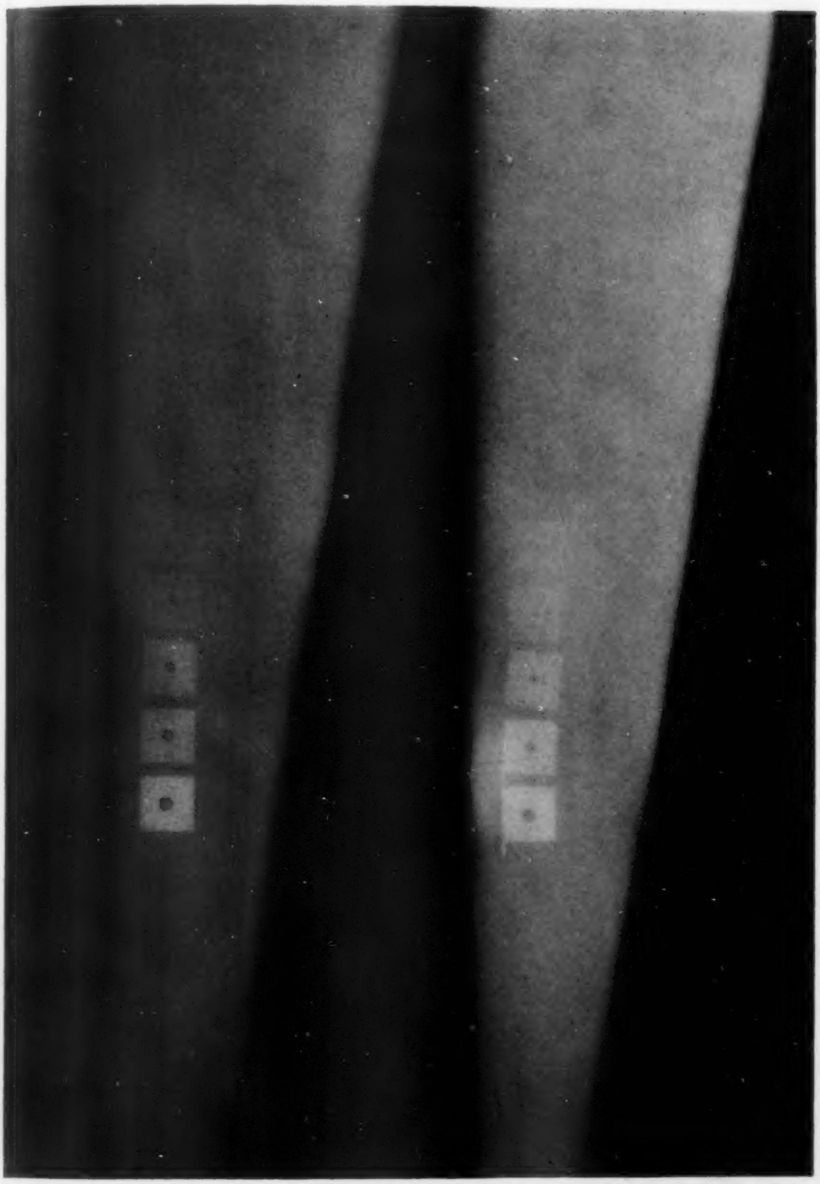
RADIOGRAPH 6—CENTER-LINE SHRINKAGE IN 1-IN. THICK CASTINGS, UNPADDED,—4, 8 AND 24 IN. HIGH; 24-IN. SPECIMEN IS CUT IN TWO.—HOLES IN 8-IN. HIGH SPECIMEN MARK LOCATION OF DRILLINGS FOR CHEMICAL ANALYSIS.—SEE TABLE I FOR FINDINGS. (FIGS. 3C, 3D AND 3F IN PLATE 5)



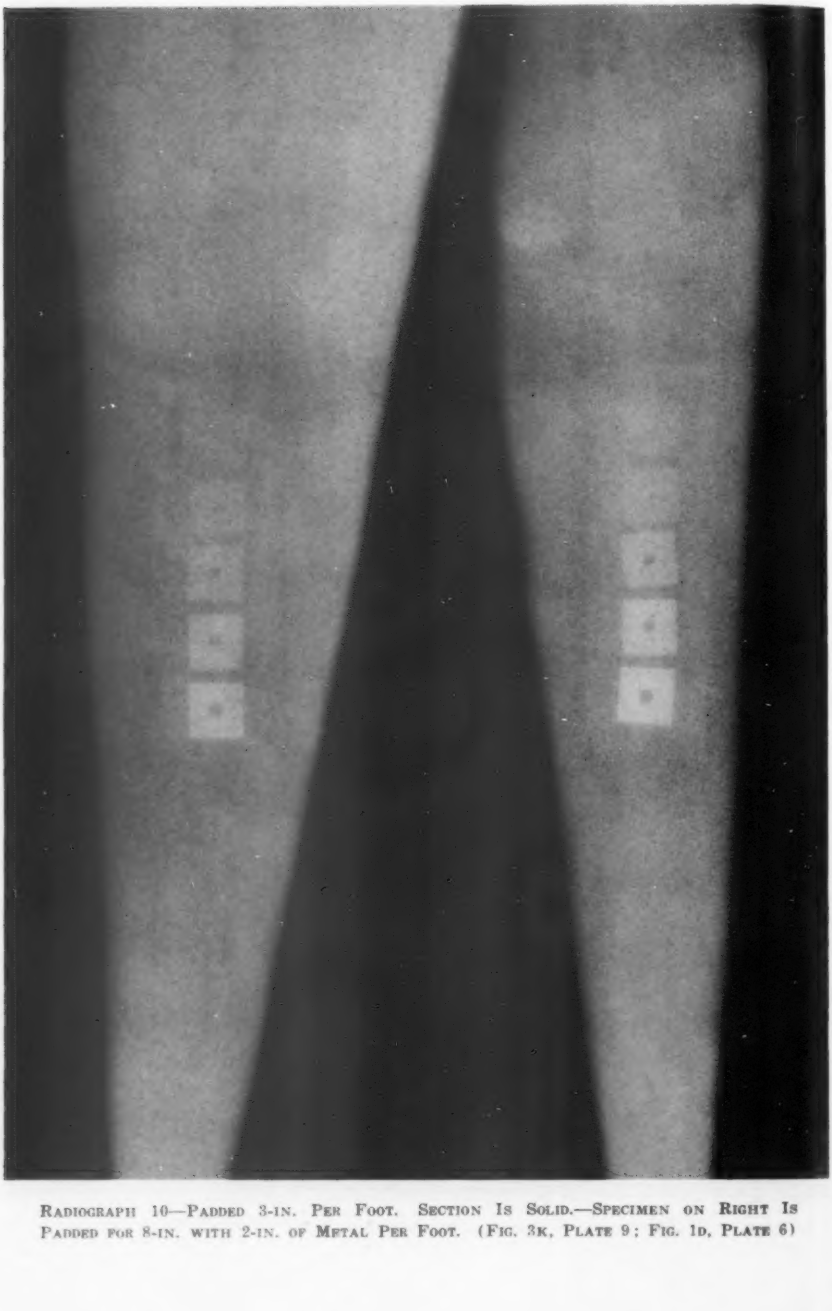
RADIOGRAPH 7—CENTER-LINE SHRINKAGE IN 1-IN. THICK SECTIONS VARIOUSLY POSITIONED IN THE MOLD.—(V)—VERTICALLY CAST; (45°) INCLINED 45°; (F)—CAST FLATWISE.—TOP SIDE OF 45° AND F SPECIMENS IS THE RIGHT SIDE.—NOTE THE TENDENCY TOWARD DISPLACEMENT OF THE CENTER-LINE SHRINKAGE TO TOP SIDE AS THE ANGLE OF TILT IS INCREASED. (FIG. 1A, PLATE 6; FIG. 4A, PLATE 7; FIG. 5A, PLATE 8)



RADIOGRAPH 8—TWO SPECIMENS ON RIGHT PADDED 1-IN. PER FOOT. (FIG. 1B, PLATE 6)

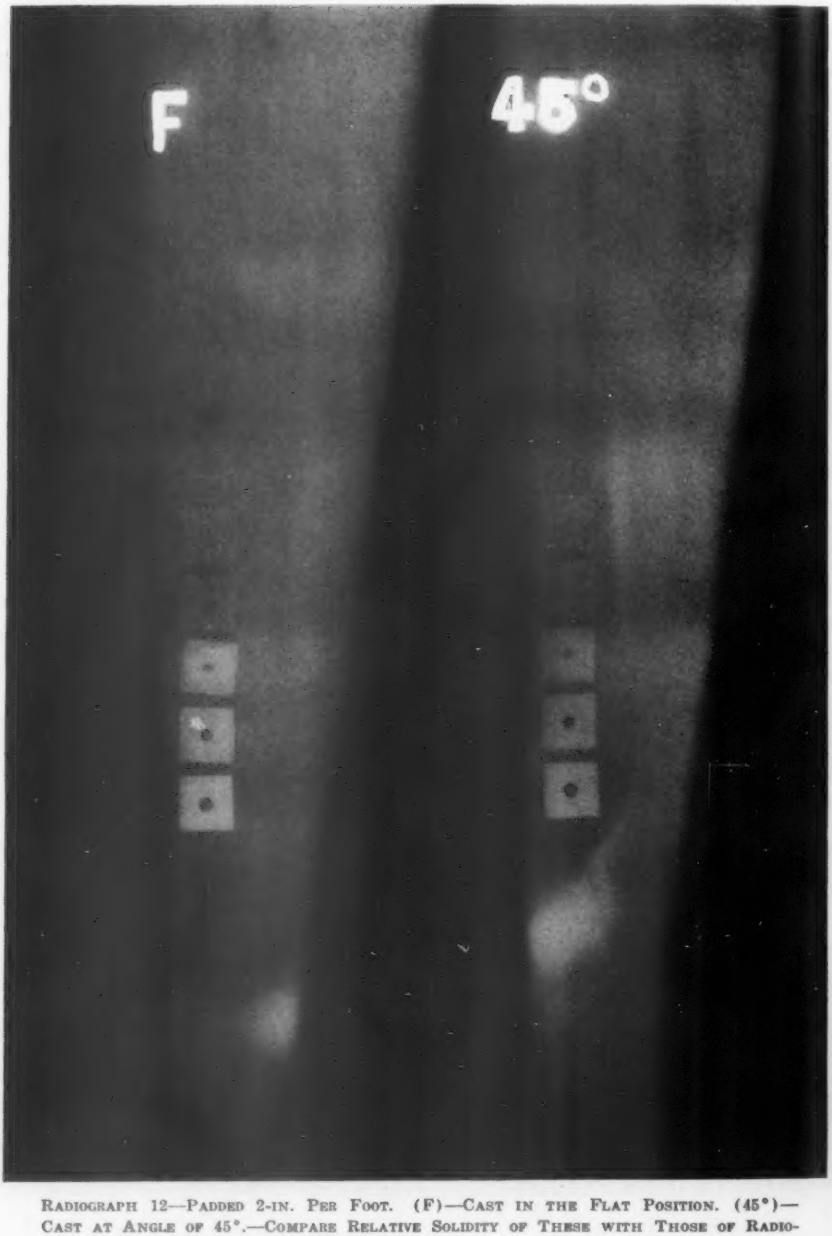


RADIOGRAPH 9—PADDED 2-IN. PER FOOT. (FIG. 1C, PLATE 6)



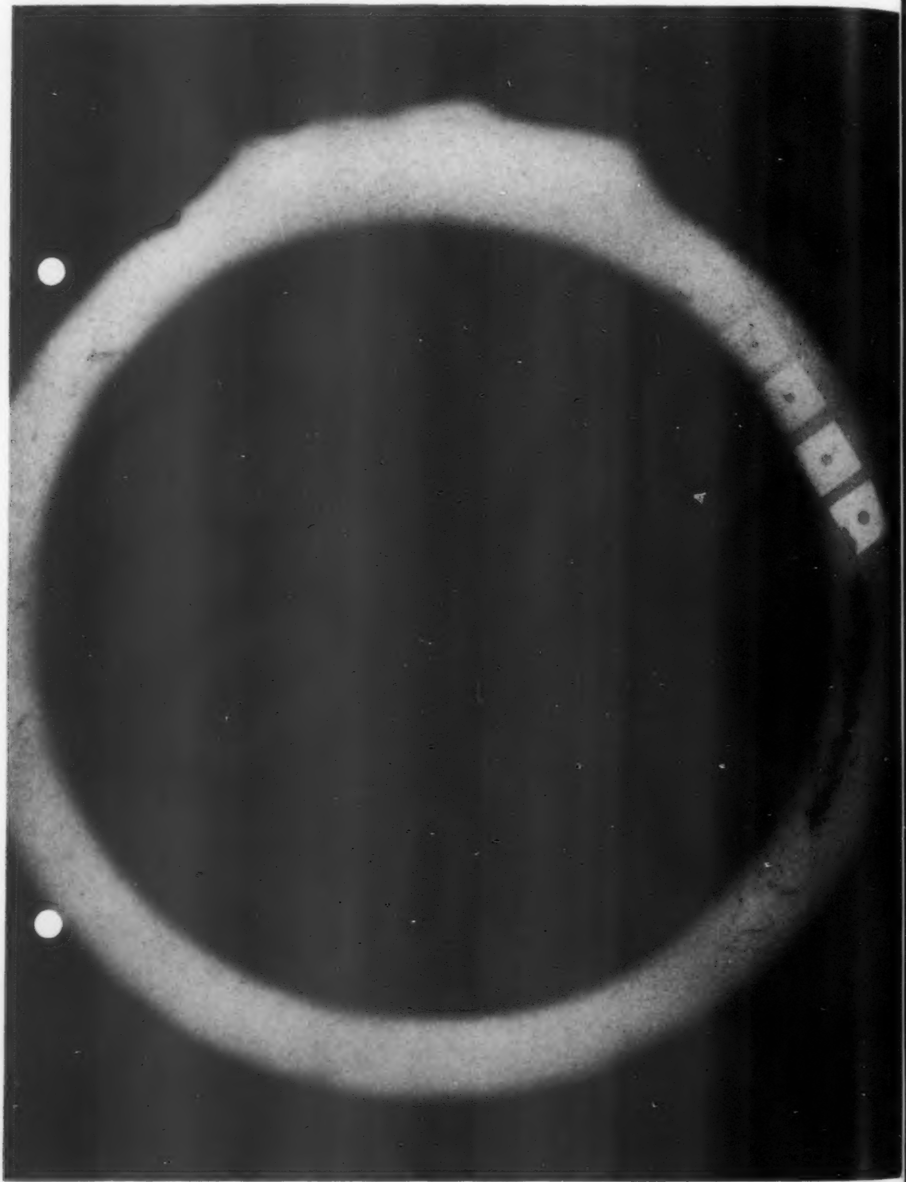
RADIOGRAPH 10—PADDED 3-IN. PER FOOT. SECTION IS SOLID.—SPECIMEN ON RIGHT IS PADDED FOR 8-IN. WITH 2-IN. OF METAL PER FOOT. (FIG. 3K, PLATE 9; FIG. 1D, PLATE 6)

RADIOGRAPH 11—COMPARATIVE RADIOGRAPH.—COMPARE SENSITIVITY OF ABOVE GAMMAGRAPH WITH FIG. 3D OF RADIOGRAPH 6.—THE DIFFERENCE IN CLARITY IS INDICATIVE OF THE FACT THAT NUMEROUS DEFECTS OF A LESS ORDER ESCAPE DETECTION.—RADIUM 25 MG. —METAL THICKNESS ½ IN.—RADIUM TO FILM, 18 IN.—EXPOSURE TIME, 4 HRS.
ALL OTHER RADIOGRAPHS IN THIS PAPER WITH THE EXCEPTION OF THIS RADIOGRAPH 11, WERE MADE BY THE USE OF X-RAYS. SEE PARAGRAPHS 24, 25 AND 36.



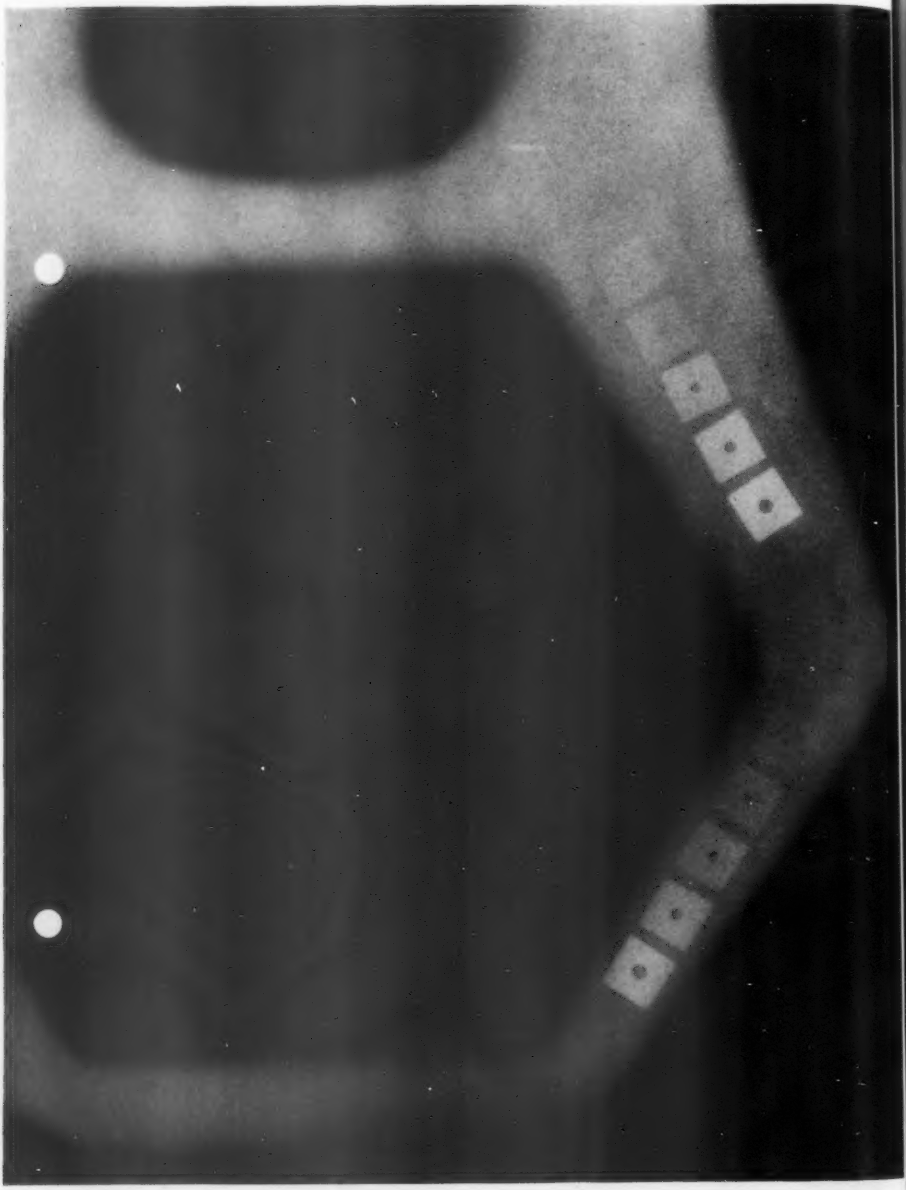
RADIOGRAPH 12—PADDED 2-IN. PER FOOT. (F)—CAST IN THE FLAT POSITION. (45°)—CAST AT ANGLE OF 45°.—COMPARE RELATIVE SOLIDITY OF THESE WITH THOSE OF RADIOGRAPH 8 WHICH WERE CAST VERTICALLY. (FIG. 4C, PLATE 7; FIG. 5C, PLATE 8)

RADIOGRAPH 13—CENTER-LINE SHRINKAGE IN 1-IN. THICK, REGULAR HEXAGON.—BORE—7-IN. BETWEEN PARALLEL FACES. (REFER TO PLATE 13)

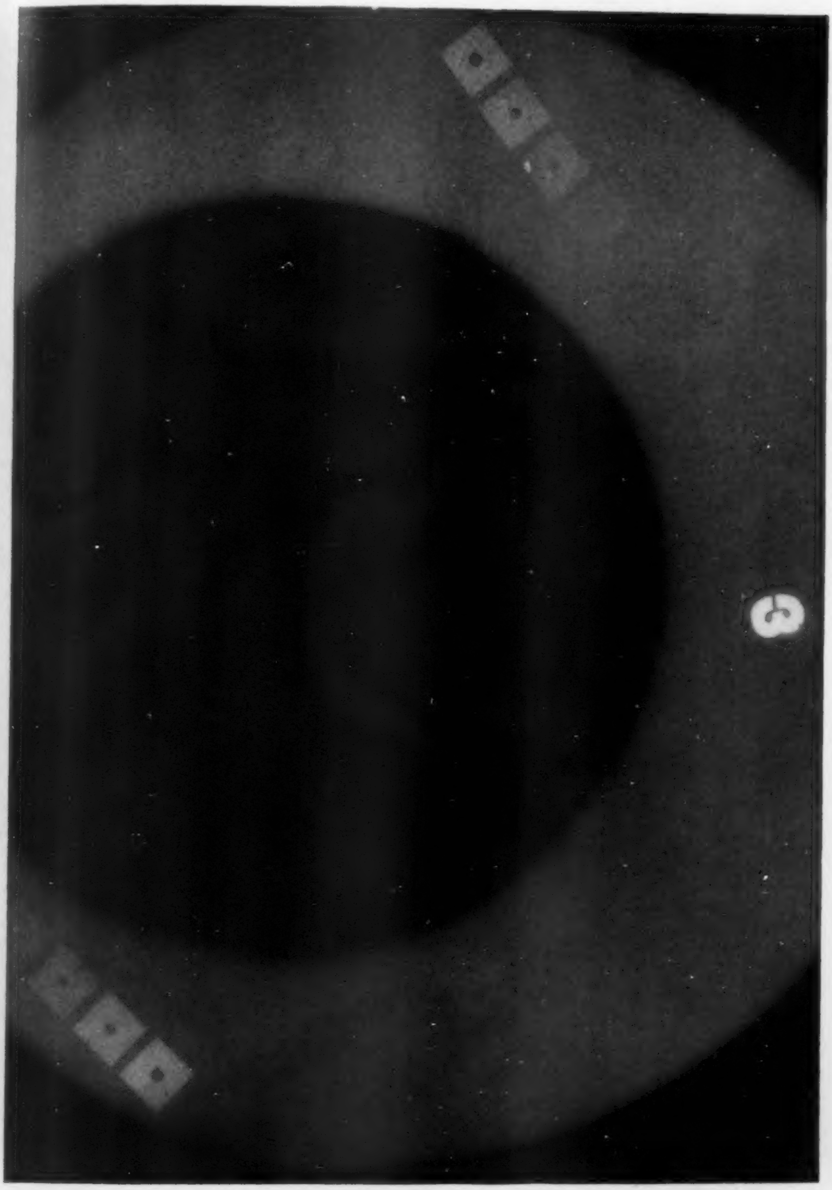


RADIOGRAPH 14—CENTER-LINE SHRINKAGE IN 1-IN. THICK CIRCULAR SECTION.—O.D. 9 IN. I.D. 7 IN. (REFER TO PLATE 14)

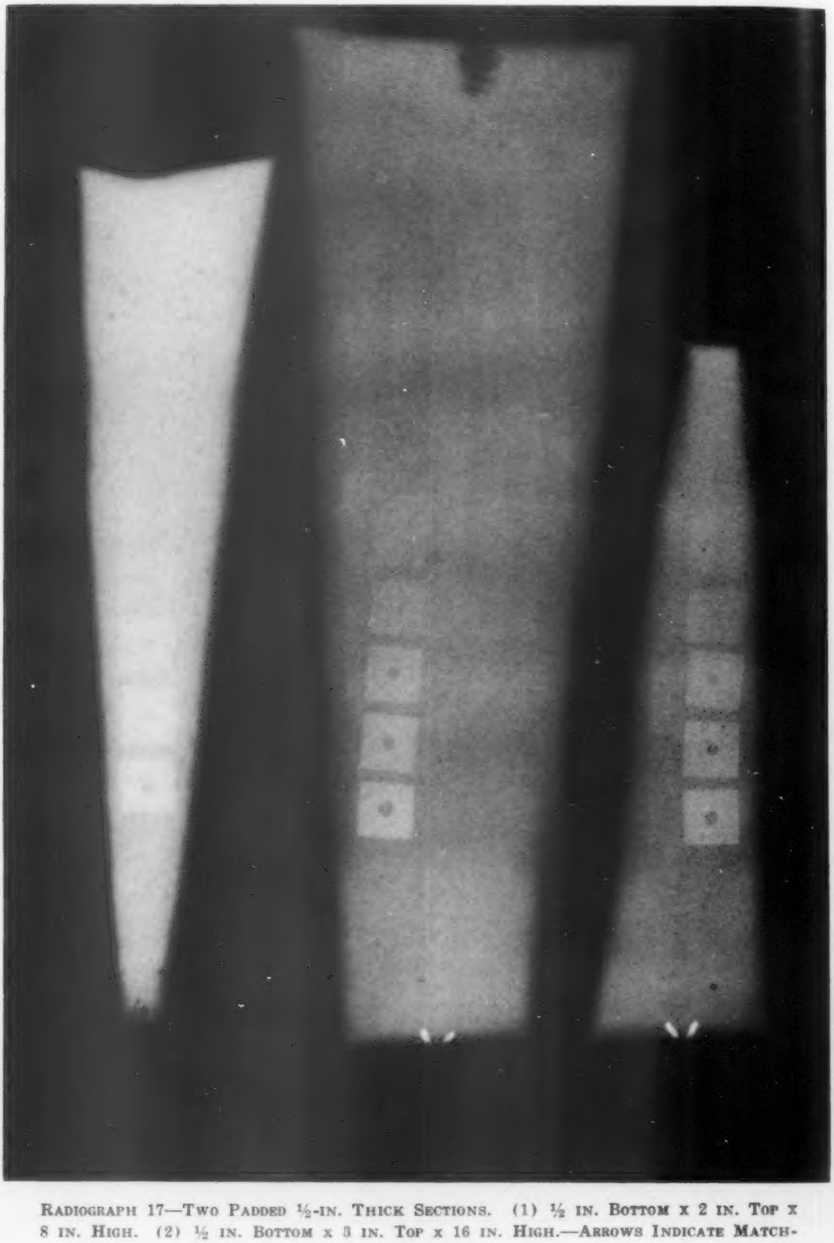
Radiograph 14b—Another View of Center-line Shrinkage in 1-in. Circular Section. —O.D. 9 in., I.D. 7 in. (Refer to Plate 14)



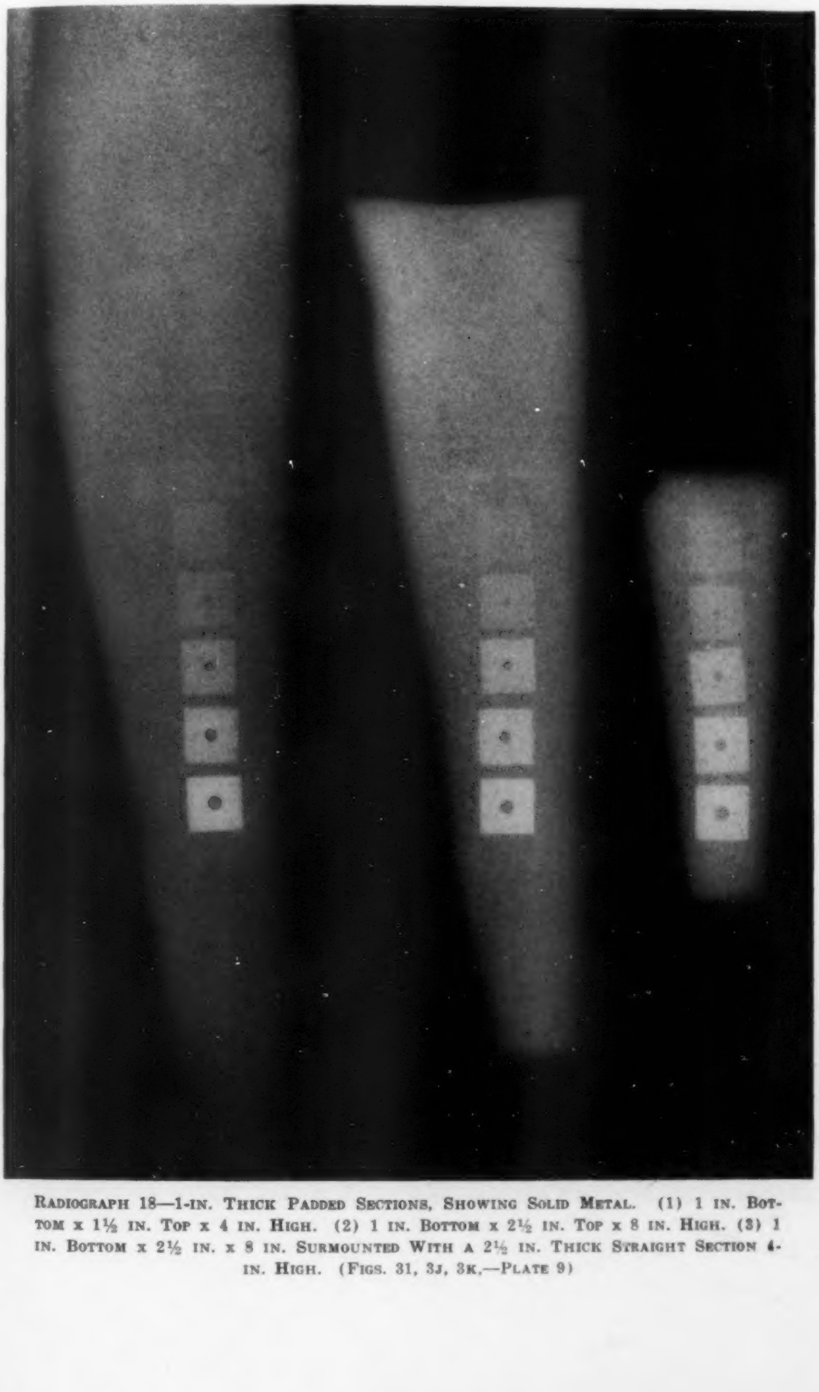
RADIOGRAPH 15—PADDED REGULAR HEXAGON.—NOTE THE UNIFORMITY AND SOLIDITY OF THE METAL STRUCTURE. BORE 7-IN. BETWEEN PARALLEL FACES. (REFER TO PLATE 15)



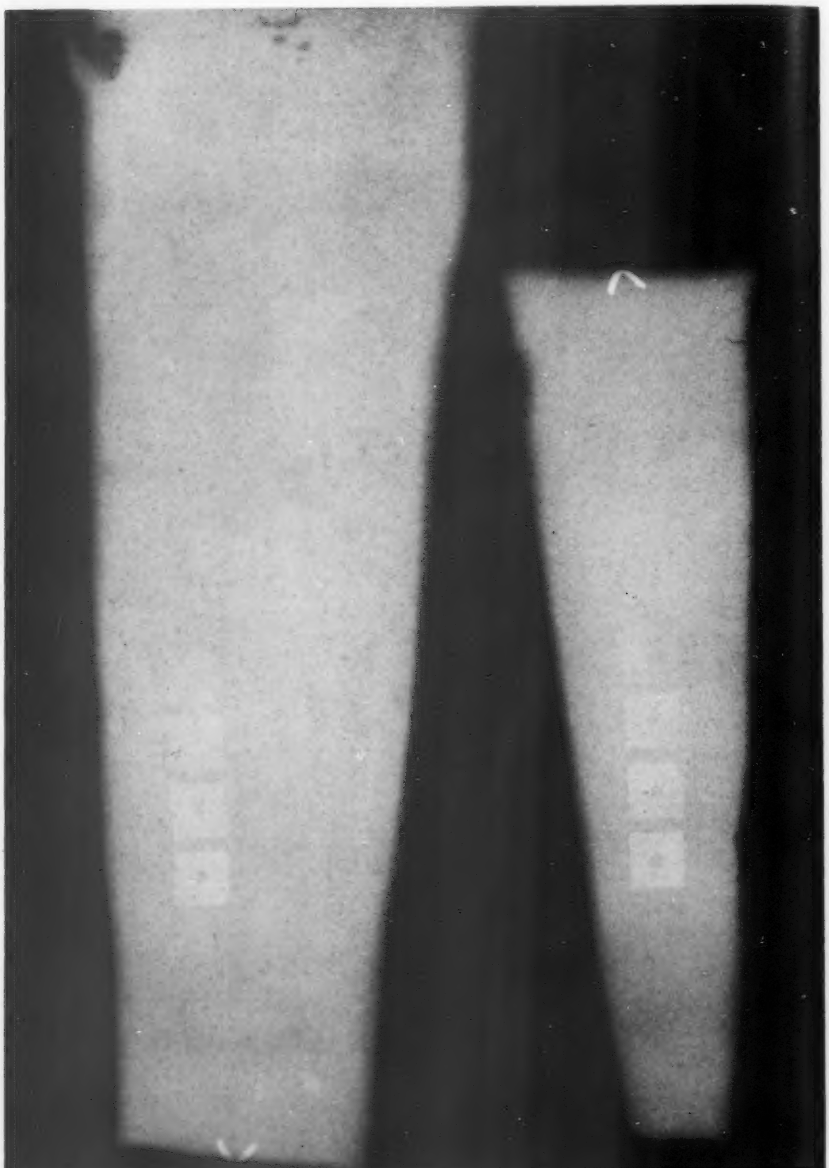
RADIOGRAPH 16—PADDED CIRCULAR SECTION.—NOTE UNIFORMITY AND SOLIDITY OF METAL STRUCTURE.—O.D. 9 IN., I.D. 7 IN. (REFER TO PLATE 16)



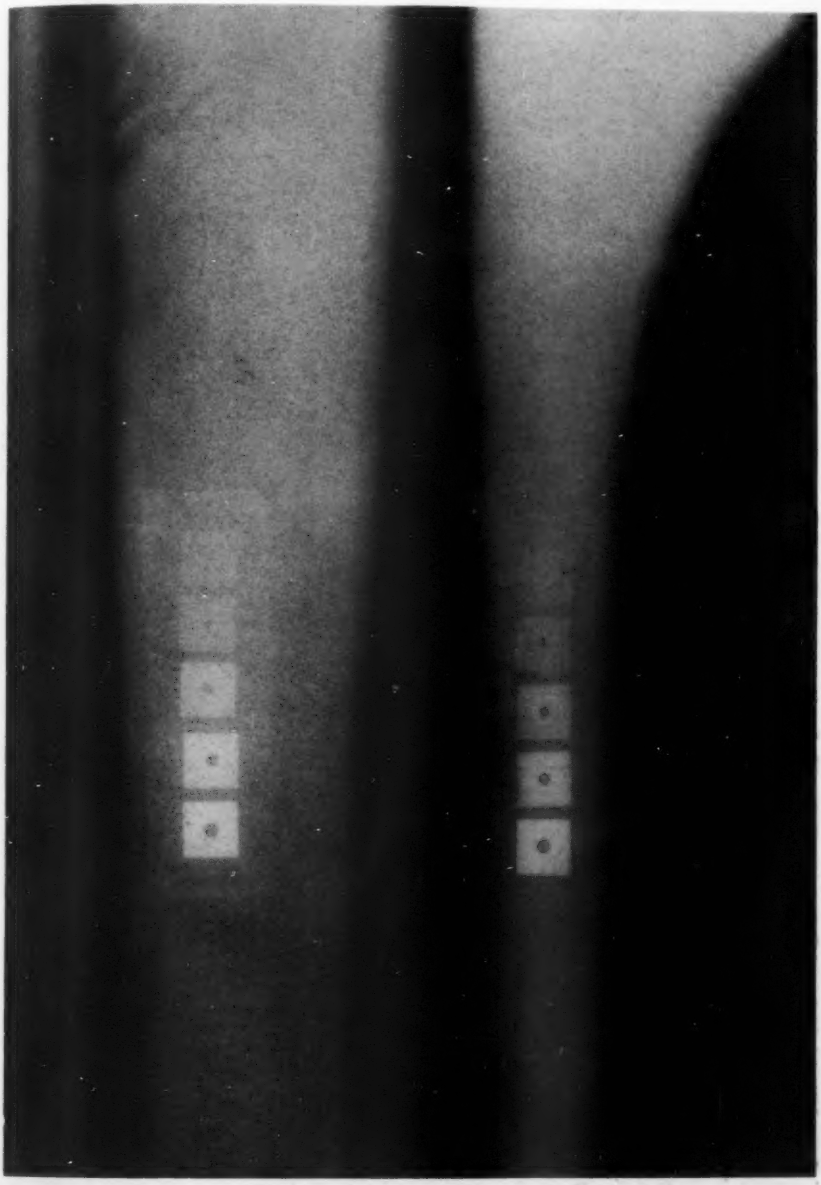
RADIOGRAPH 17—TWO PADDED ½-IN. THICK SECTIONS. (1) ½ IN. BOTTOM x 2 IN. TOP x 8 IN. HIGH. (2) ½ IN. BOTTOM x 3 IN. TOP x 16 IN. HIGH.—ARROWS INDICATE MATCHING FACES OF SPECIMEN CUT IN TWO.—SECTIONS ARE SOLID THROUGHOUT. (FIG. 6B, PLATE 10; 6F, PLATE 11)



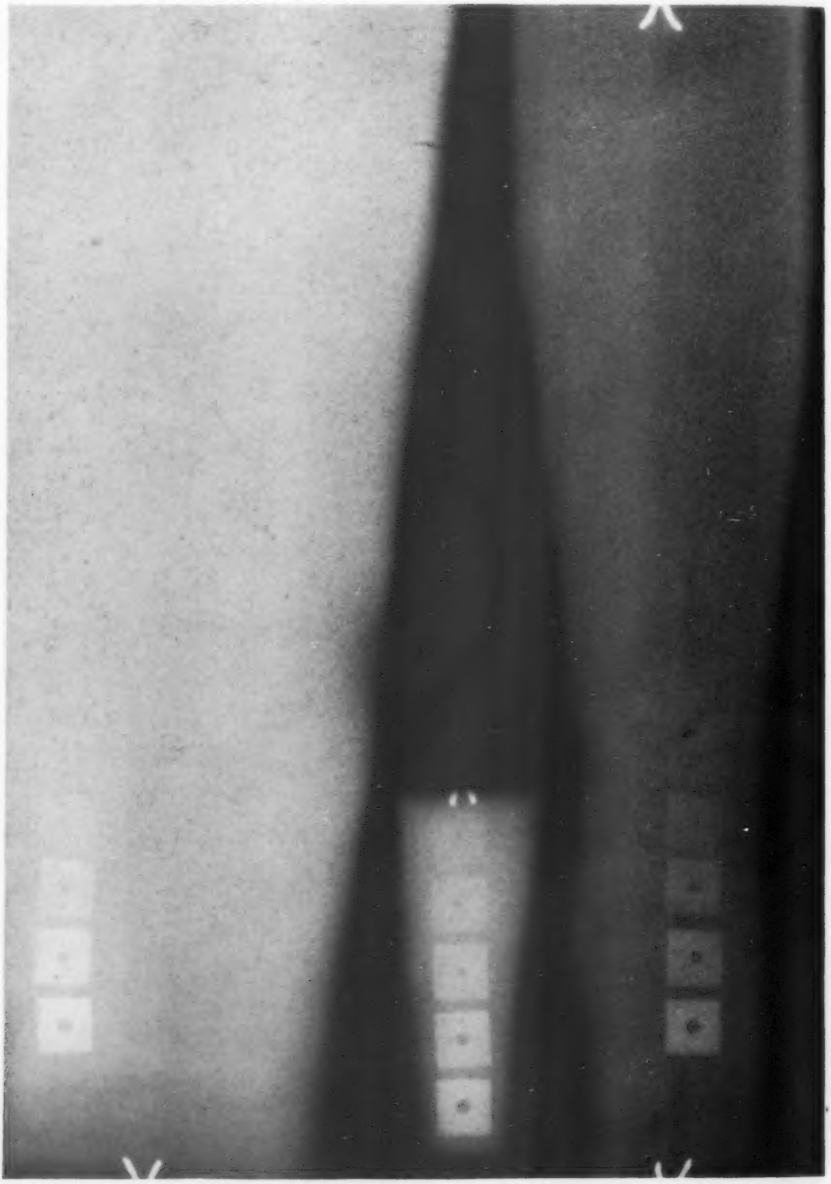
RADIOGRAPH 18—1-IN. THICK PADDED SECTIONS, SHOWING SOLID METAL. (1) 1 IN. BOTTOM x 1½ IN. TOP x 4 IN. HIGH. (2) 1 IN. BOTTOM x 2½ IN. TOP x 8 IN. HIGH. (3) 1 IN. BOTTOM x 2½ IN. x 8 IN. SURMOUNTED WITH A 2½ IN. THICK STRAIGHT SECTION 4-IN. HIGH. (FIGS. 3I, 3J, 3K,—PLATE 9)



RADIOGRAPH 19—1-IN. THICK PADDED SECTION. (1) 1 IN. BOTTOM x 4 IN. TOP x 20 IN. HIGH.—VEES INDICATE MATCHING FACES.—NO EVIDENCE OF CENTER-LINE SHRINKAGE IS EVIDENT IN EITHER HALF. (FIG. 3M, PLATE 9)

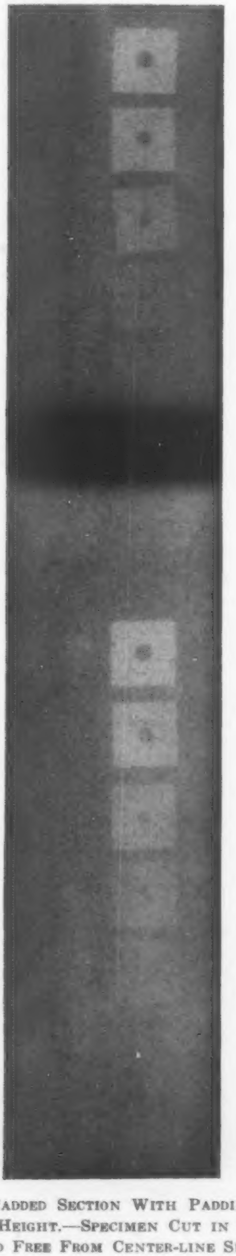


RADIOGRAPH 20—1-IN. THICK PADDED SECTIONS. (1) 1 IN. BOTTOM x 3 IN. TOP x 24 IN. HIGH.—UPPER HALF. (LOWER HALF OF SPECIMEN LEFT OUT). (2) 1 IN. BOTTOM x 4 IN. TOP x 12 IN. HIGH, SPECIAL TAPERED DESIGN.—NOTE FAINT TRACES OF CENTER-LINE SHRINKAGE REMNANT IN THE STRAIGHT TAPERED SPECIMEN. (FIG. 3N, PLATE 9; FIG. 1F, PLATE 6)

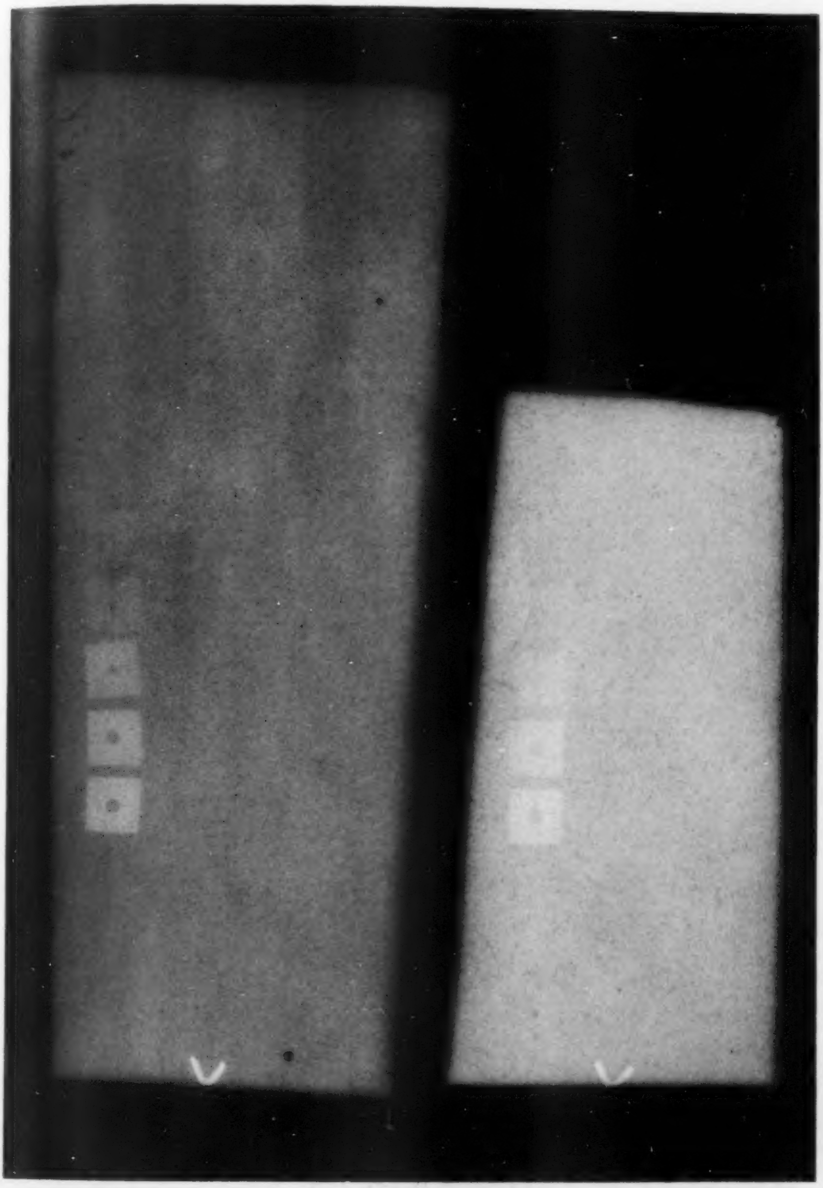


RADIOGRAPH 21—1-IN. THICK PADDED SECTION. (1) 1 IN. BOTTOM x 4¾ IN. TOP x 28 IN. HIGH.—VEES INDICATE MATCHING FACES.—SLIGHT EVIDENCE OF CENTER-LINE SHRINKAGE IS REGISTERED IN AREAS IMMEDIATELY ABOVE THE BULGES. (FIG. 3Q, PLATE 9)

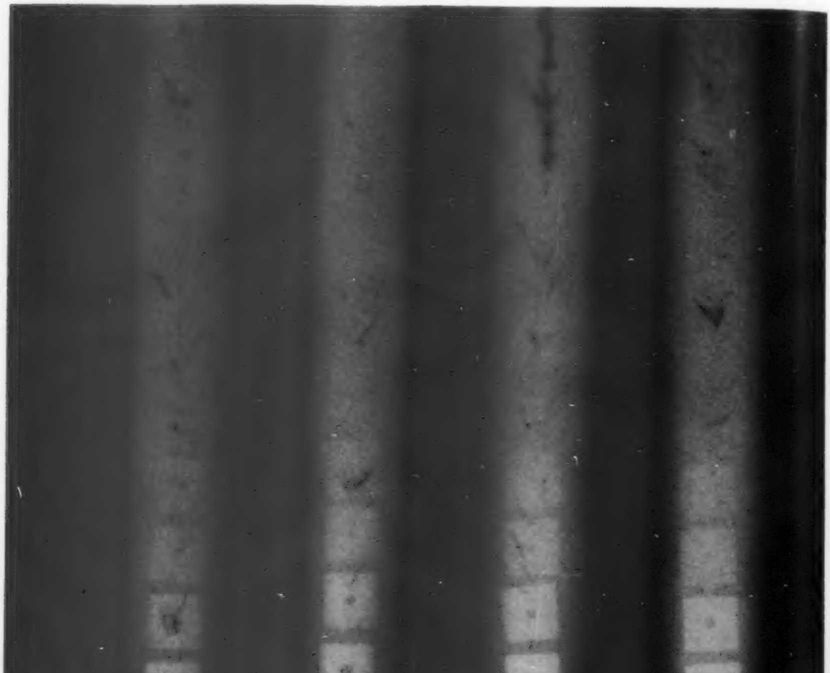
RADIOGRAPH 22—2-IN. THICK PADDED SECTION. (1) 2 IN. BOTTOM X 3⅞ IN. TOP X 20 IN. HIGH.—VEES INDICATE MATCHING FACES.—SHOWING EVIDENCE OF PINHOLE POROSITY, BUT NOT OF CENTER-LINE SHRINKAGE. (FIG. 6J, PLATE 11)



RADIOGRAPH 23—2-IN. THICK PADDED SECTION WITH PADDING MACHINED OFF. (1). 2 IN. BOTTOM x 4 IN. TOP x 12 IN. HEIGHT.—SPECIMEN CUT IN TWO FOR MICROSCOPIC EXAMINATION.—SECTION IS SOUND AND FREE FROM CENTER-LINE SHRINKAGE. (FIG. 3A, PLATE 4)



RADIOGRAPH 24—3-IN. THICK PADDED SECTION. (1) 3-IN. BOTTOM x 3¾ IN. TOP x 16 IN. HIGH.—VEES INDICATE MATCHING FACES.—NOTE ABSENCE OF CENTER-LINE SHRINKAGE. (FIG. 6G, PLATE 11)

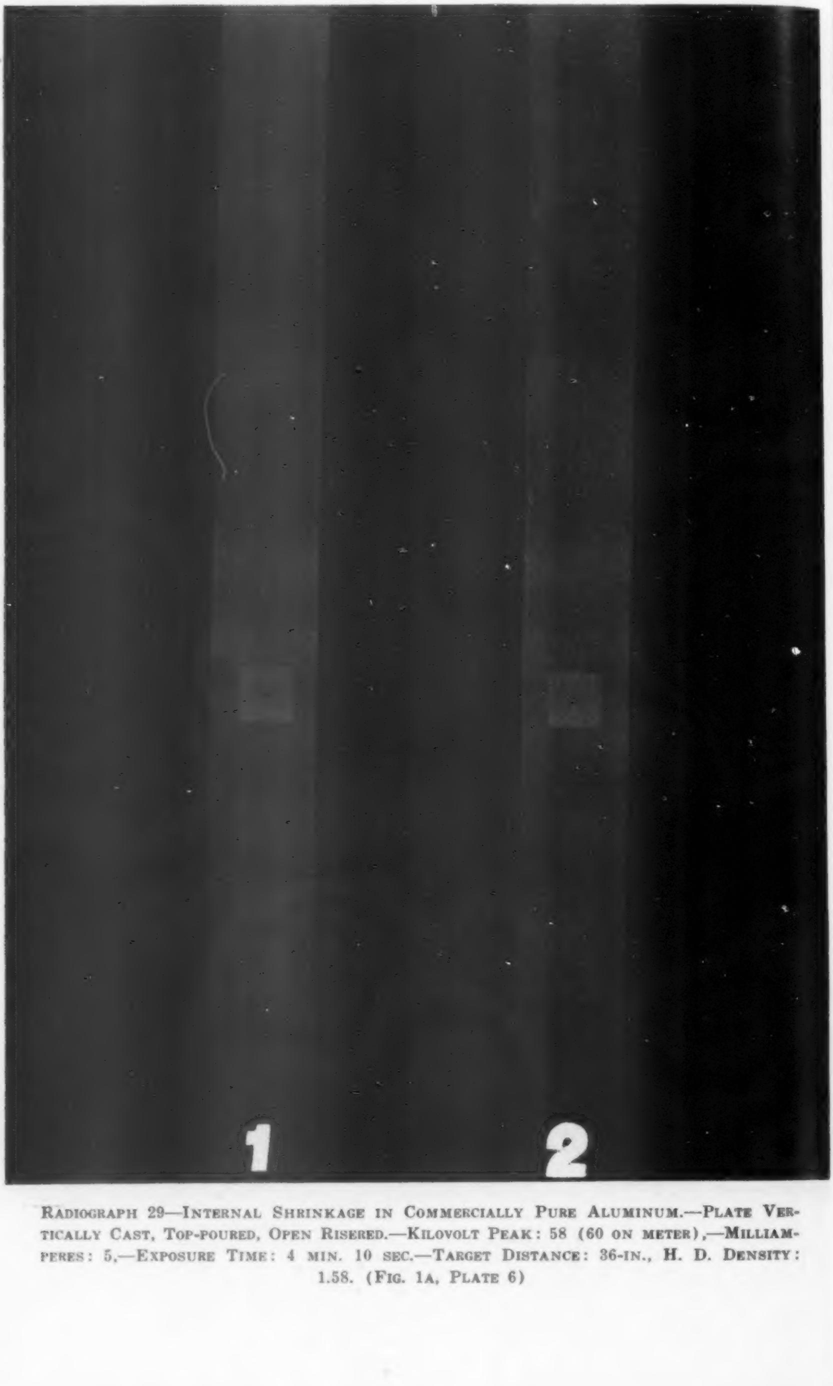


RADIOGRAPH 25—CENTER-LINE SHRINKAGE IN 1-IN. THICK SECTIONS CAST AT DIFFERENT TEMPERATURES. (1) CAST AT APPROXIMATELY 3130°F., (2) CAST AT APPROXIMATELY 2990°F., (3) CAST AT APPROXIMATELY 2850°F., (4) CAST AT APPROXIMATELY 2780°F. (FIG. 1A, PLATE 6)

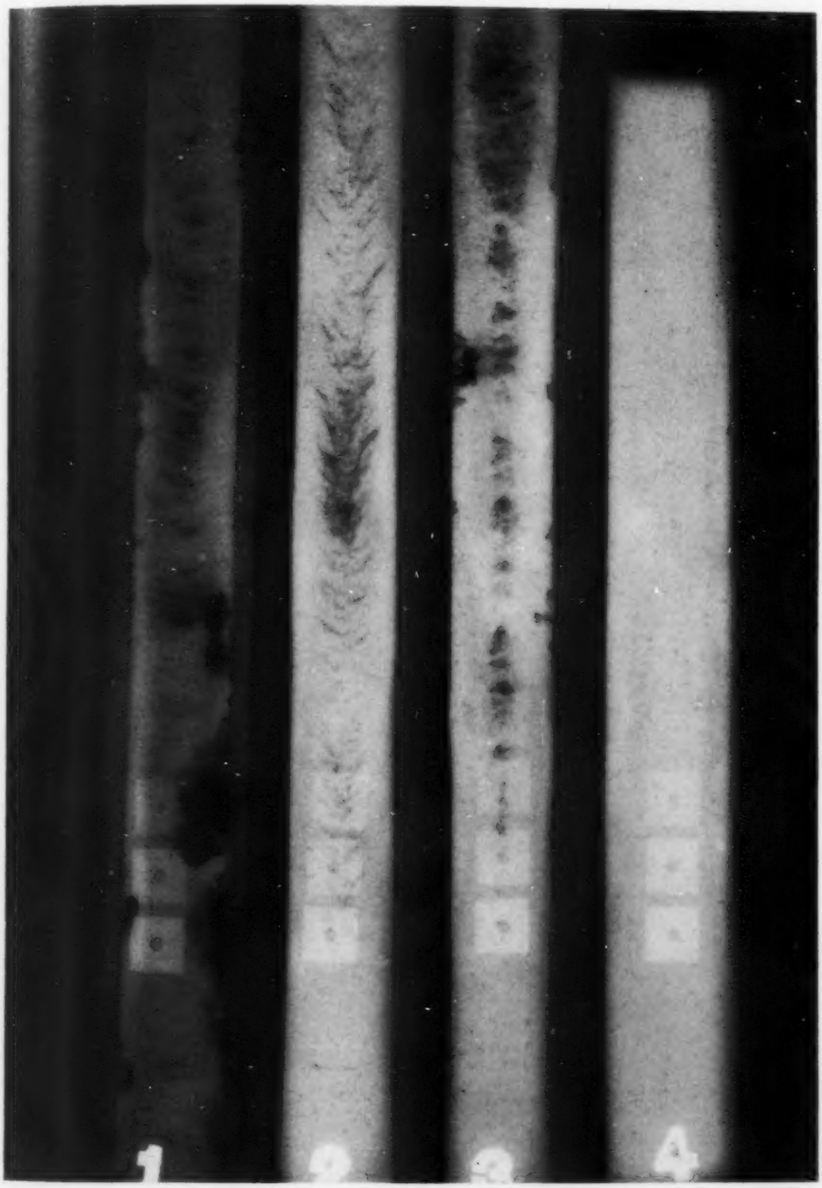
RADIOGRAPH 26—CENTER-LINE SHRINKAGE IN THREE 1-IN. THICK SECTIONS FED FROM 2 BLIND RISERS EACH.—THIRD SPECIMEN—LEFT TO RIGHT—WAS NOT BLIND RISERED.—NOTE INVERTED SHRINKAGE CHEVRONS. (FIG. 1A, PLATE 6)

RADIOGRAPH 27—SHOWING CONDITION OF METAL IN "C" (CHILL-CAST) AND "H" (PRE-HEATED MOLD) SECTIONS 1-IN. THICK.—OBSERVE THE SOLIDITY OF THE ONE AND THE DEFECTIVE CONDITION OF THE OTHER. (FIG. 1A, PLATE 6)

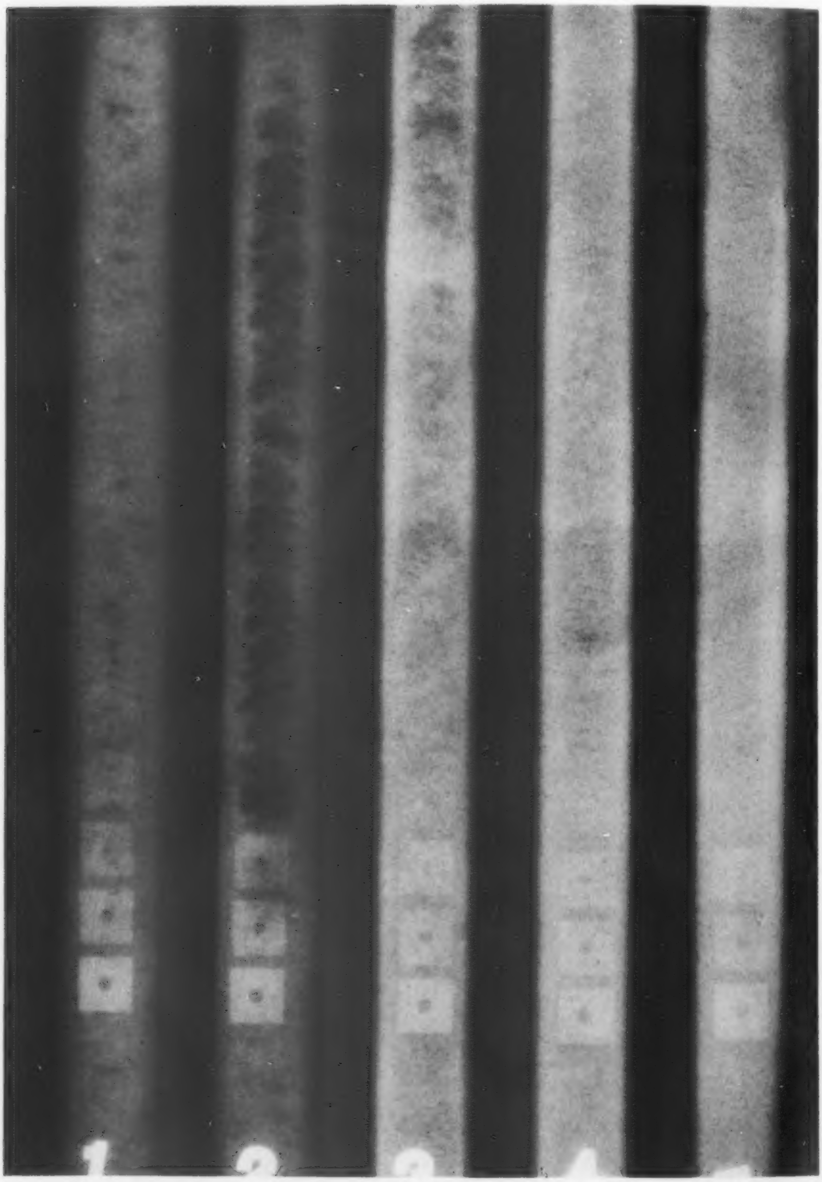
RADIOGRAPH 28—CENTER-LINE SHRINKAGE IN DEOXIDIZED COPPER.—PLATE VERTICALLY CAST, TOP-POURED, OPEN RISERED.—KILOVOLT PEAK: 120,—MILLIAMPERES: 10,—EXPOSURE TIME: 2 MIN.,—TARGET DISTANCE: 36 IN.,—H.D. DENSITY: 1.26. (FIG. 1A, PLATE 6)



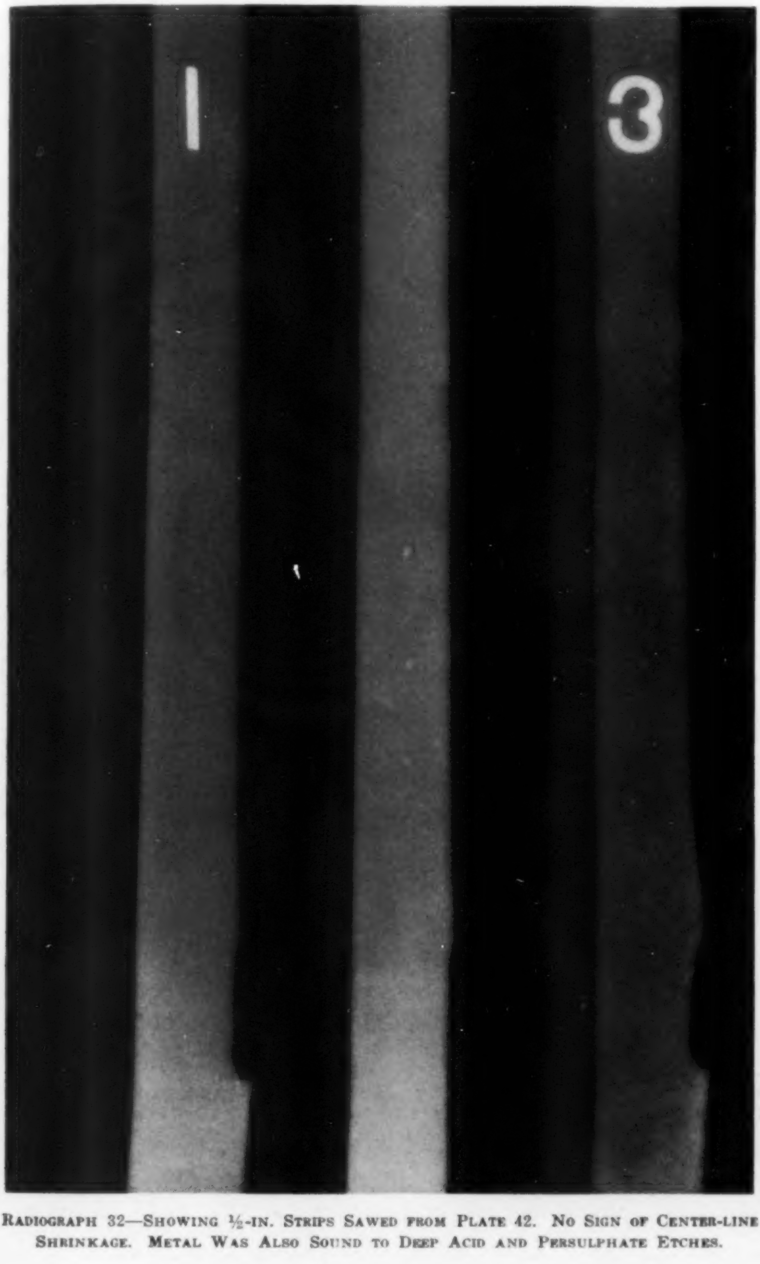
RADIOGRAPH 29—INTERNAL SHRINKAGE IN COMMERCIALLY PURE ALUMINUM.—PLATE VERTICALLY CAST, TOP-POURED, OPEN RISERED.—KILOVOLT PEAK: 58 (60 ON METER),—MILLIAMPERES: 5,—EXPOSURE TIME: 4 MIN. 10 SEC.—TARGET DISTANCE: 36-IN., H. D. DENSITY: 1.58. (FIG. 1A, PLATE 6)



RADIOGRAPH 30—LEFT TO RIGHT, SHOWING CENTER-LINE SHRINKAGE IN: (1) CRS, TOP-POURED, OPEN RISERED, (2) NI-CU-SI ALLOY, TOP-POURED, OPEN RISERED, (3) NI-CU-SI ALLOY, BOTTOM-POURED, DOUBLE BLIND RISERED, (4) MANGANESE BRONZE, TOP-POURED, OPEN RISERED. 120 VOLTS—10 MILLIAMPERES—4 MIN.—36 IN. (FIG. 1A, PLATE 6)

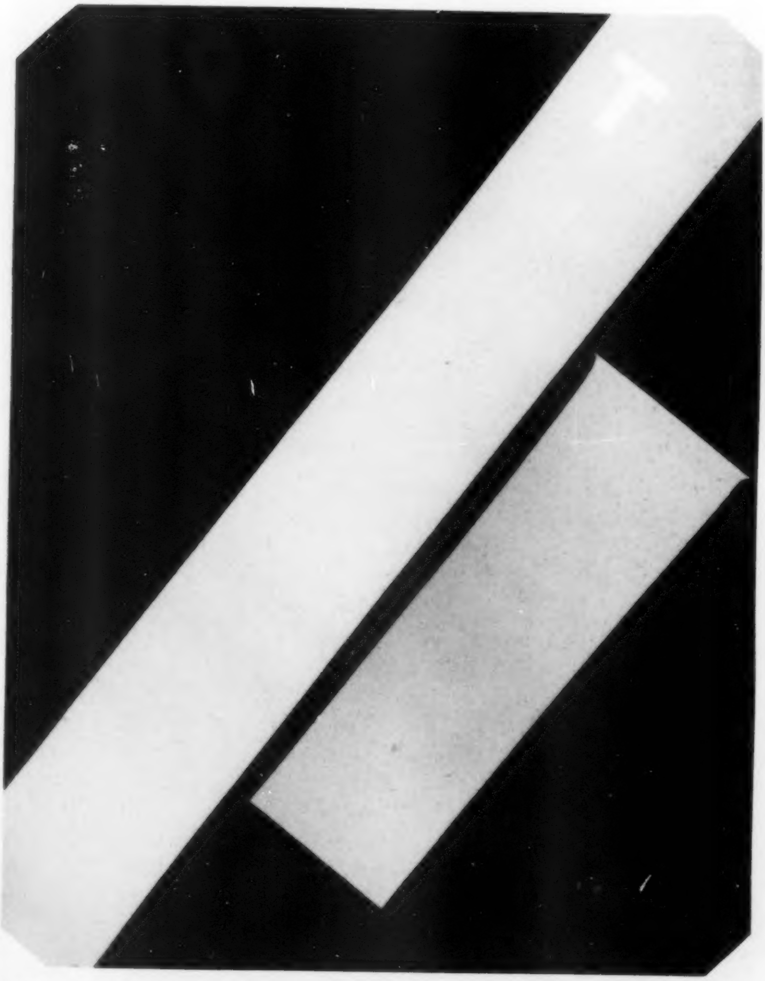


RADIOGRAPH 31—LEFT TO RIGHT, SHOWING CENTER-LINE SHRINKAGE IN: (1) CU-SI ALLOY, BOTTOM-POURED, OPEN RISERED. (2) CU-SI ALLOY, BOTTOM-POURED, DOUBLE BLIND RISERED. (3) GUN METAL, BOTTOM-POURED, DOUBLE BLIND RISERED. (4) GUN METAL, BOTTOM-POURED, DOUBLE BLIND RISERED. (5) GUN METAL, TOP-POURED, OPEN-RISERED.—140 KVP —10 MILLIAMPERES—1 MIN.—36 IN. (FIG. 1A, PLATE 6)

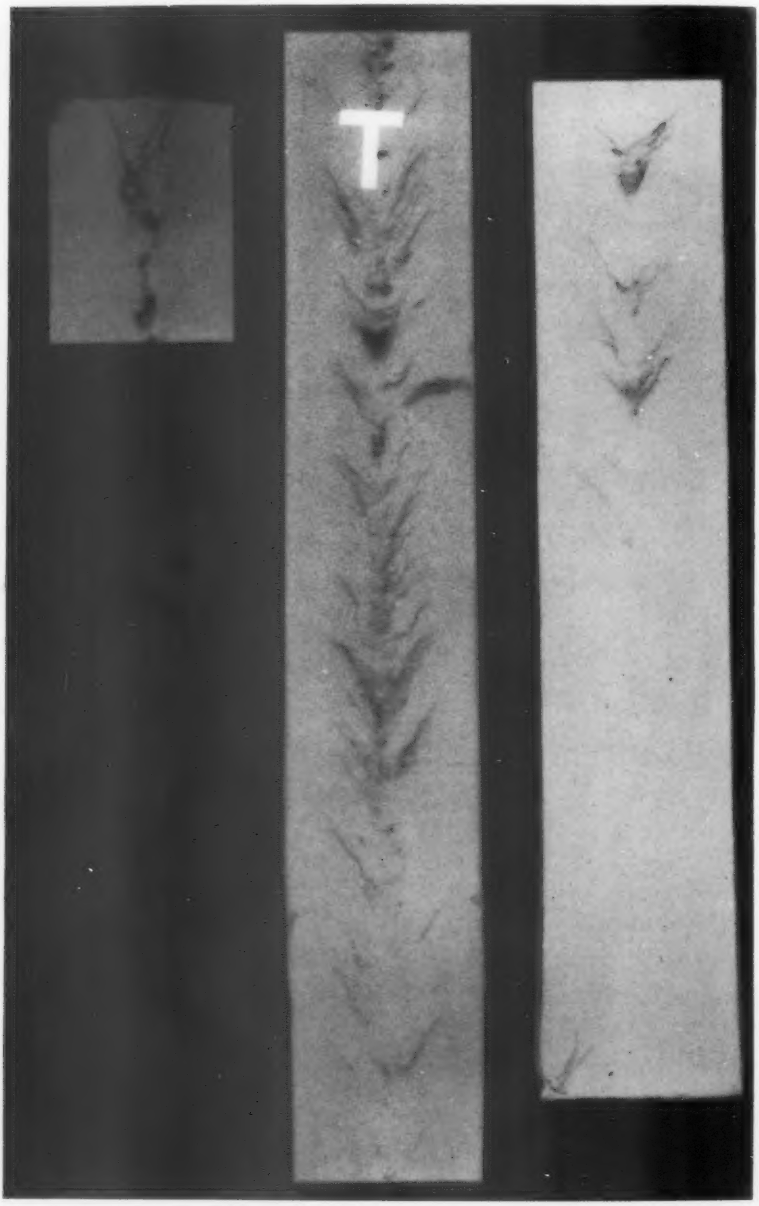


RADIOGRAPH 32—SHOWING ½-IN. STRIPS SAWED FROM PLATE 42. NO SIGN OF CENTER-LINE SHRINKAGE. METAL WAS ALSO SOUND TO DEEP ACID AND PERSULPHATE ETCHES.

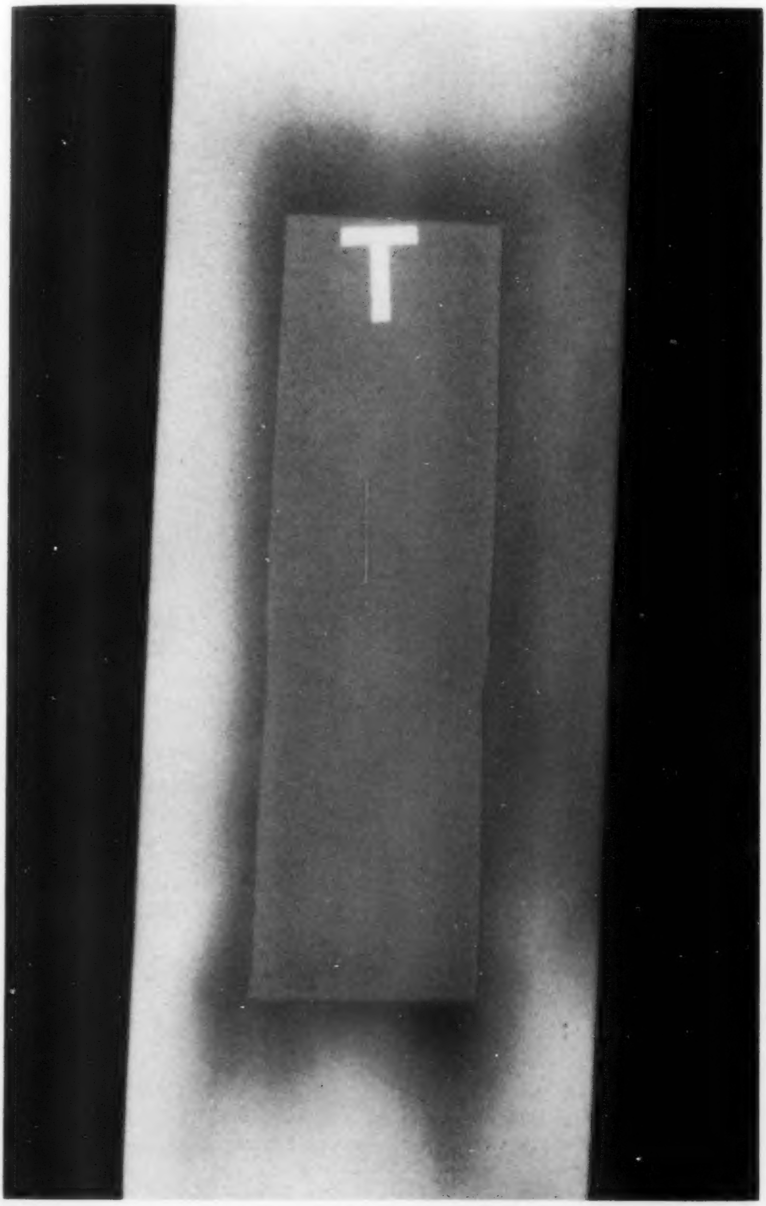
RADIOGRAPH 33—SHOWING CONDITION OF STRIP 1 SAWED FROM PLATE 43, STRIPS 2 AND 3 FROM PLATE 44, STRIP 4 FROM PLATE 45, AND STRIP 5 FROM PLATE 42. STRIPS 1, 2, 3 AND 4 SHOWED CASTINGS UNSOUND IN VARYING DEGREES. STRIP 5 SHOWED CASTING PERFECTLY SOUND.



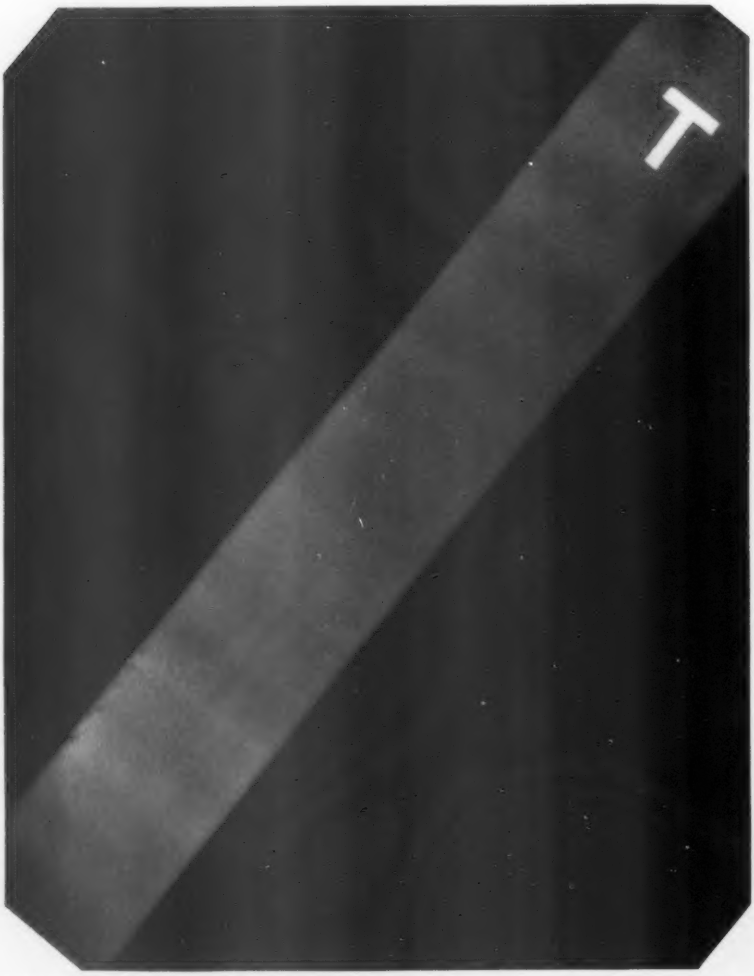
RADIOGRAPH 34—SHOWING CONDITION OF STRIP SAWED FROM PLATE 46. NO CENTER-LINE SHRINKAGE PRESENT.



RADIOGRAPH 35—SHOWING CONDITION OF STRIP SAWED FROM PLATE 47. CENTER-LINE SHRINKAGE PRESENT.



RADIOGRAPH 36—SHOWING CONDITION OF STRIP SAWED FROM PLATE 48. NO CENTER-LINE SHRINKAGE PRESENT.



RADIOGRAPH 37-A—SHOWING CONDITION OF UPPER HALF OF STRIP SAWED FROM PLATE 49. NO CENTER-LINE SHRINKAGE PRESENT.

Radiograph 37-B—Showing Condition of Lower Half of Strip Sawed from Plate 49. Center-line Shrinkage Present.

Secondary Aluminum for Sand Castings

By W. E. Martin*, Brooklyn, N. Y.

Abstract

Government specifications for aluminum castings for many years have been based on the use of virgin aluminum ingot. However, with the advent of the war and the scarcity of virgin aluminum, it has been necessary to utilize the so-called secondary aluminum in war work. The author and his company have made an extensive study to adapt secondary aluminum to their products and have been successful. This paper is offered as an aid to those companies which will find it necessary to use secondary aluminum alloys in their foundries instead of virgin aluminum alloys. The author gives the chemical and physical requirements necessary to meet government specifications and stresses the fact that the secondary material must not contain more than 0.10 per cent magnesium in order to meet said specifications. Figures and tables are included which give results of tests performed.

1. As the result of recent W.P.B. restrictions on the use of primary aluminum, a large part of the castings used in the defense effort must hereafter be made of secondary aluminum. The work discussed in this paper was initiated in the Sperry Gyroscope Company Materials Laboratory in January, 1942, at which time it was apparent that such restrictions would eventually come about. In the meantime, a substantial number of the castings used in Sperry non-flying equipment have been and are being produced of secondary aluminum. Work is now under way to convert castings used in Sperry aircraft equipment to secondary metal as quickly and completely as possible—the notable exceptions being castings used in aircraft structures. We have had some trouble in the changeover, and had it not been made gradually and with considerable experimental work, serious production delays would have resulted. This paper is presented with the hope that, by pointing out the dangers involved as determined by our work, some production delays and equipment failures may be prevented somewhere in the defense industry.

* Materials Laboratory, Sperry Gyroscope Co.

REQUIREMENTS OF A SECONDARY ALLOY

2. Most aluminum alloys as produced by primary aluminum producers are made from virgin metal and contain extremely small percentages of impurities. For some purposes, it is important that these impurities be maintained at the low limits which have been set by most government specifications. However, it is impossible, when reclaiming turnings, borings, scrap, stampings, and spoiled work, to keep the impurities at the limits set by these virgin metal specifications. The term "secondary aluminum" has been applied to this reclaimed material.

3. It has become extremely important to utilize all aluminum available in the country for defense work. The secondary material will be a mixture of silicon-bearing aluminum, copper-bearing aluminum, and other miscellaneous grades. Because of the impossibility of keeping all scrap segregated on the basis of its original analysis, any secondary composition readily available must be a blend of the metal available to the smelters.

4. To be useful to the foundries, the secondary material must cast well, should be reasonably easy to straighten, and, for our purposes, must machine at least as well as the primary materials which we have been using, and must have satisfactory mechanical properties. It has been agreed by all the procurement boards that a lower corrosion resistance will be acceptable. From previous experience in the casting of intricate instrument parts, it had been determined that a minimum silicon content of 3¼ per cent should be maintained. After numerous conversations with the secondary smelters, it was determined that an alloy having approximately 3 per cent copper and 4 per cent silicon should be available in sufficient quantities to cover the production of our equipment. It was further determined that an alloy of 3 per cent silicon and 4 per cent copper would be the most available secondary alloy.

TESTS

5. On the basis of preliminary information, some large and intricate parts were cast of metal having the composition listed in Table 1 as alloy No. 40. Considerable cracking, lack of weldability and poor straightening properties were developed by this material. This material was not considered usable. Therefore, a series of tests was undertaken to try to determine the effects of impurities.

Table 1

COMPOSITION OF HEATS STUDIED IN THE INVESTIGATION

Heat	*Copper*	*Silicon*	*Magnesium*	*Iron*	*Nickel*	*Manganese*	*Zinc*
Alloy 40	2.75	3.50	0.48	0.95	0.26	0.13	0.48
40K	2.38	3.55	0.08	1.28	0.50	0.22	0.10
40L	2.25	2.30	0.02	0.70	0.09	0.38	0.04
40D	2.38	3.55	0.41	1.28	0.50	0.22	0.10
40M	3.00	4.25	0.04	0.93	0.12	0.50	0.05
40B	2.64	3.37	0.16	1.19	0.54	0.20	0.43
40P	311	4.18	0.10	0.80	0.10	0.20	0.42
40Q	4.10	2.15	0.01	0.81	0.07	0.36	0.14

6. It will be noted that the material used in the above test contained approximately 0.5 per cent magnesium. Scrap, as received by the secondary smelters, normally contains magnesium varying from 0.2 to 1.0. It was suspected that magnesium was the element causing the embrittlement in these first castings made. To find the effect of magnesium, a series of tests was run covering magnesium contents of from 0.02 per cent to 0.41 per cent. Tests were also run varying the copper and silicon contents, and a reasonably complete coverage of other impurities was made. Castings, transverse test bars and standard 0.505-in. diameter test bars were made in sufficient quantities to establish the mechanical properties and the effects of various heat treatments. Fairly early in the test, anodizing and machining tests were conducted. Preliminary tests were made on the dimensional stability of the alloys in question.

Table 2

CHEMICAL AND PHYSICAL LIMITS OF SECONDARY ALLOY NO. 18 SAND CASTINGS

Chemical Requirements	
Element	*Per Cent*
Copper	2.25 to 3.5
Silicon	3.25 to 4.5
Magnesium	0.10 Max.
Iron	0.9 Max.
Nickel	0.4 Max.
Manganese	0.6 Max.
Zinc	0.6 Max.
Others Total	0.5 Max.
Aluminum	Remainder
†Physical Requirements	
*Yield Strength, p.s.i.	15,000 Min.
Tensile Strength, p.s.i.	23,000 Min.
Elongation, per cent in 2-in.	1.5 Min.

† As heat treated for 5 hours at 450°F.

* Stress required to produce 0.2 per cent offset from the modulus line.

TEST RESULTS

7. On the basis of the work performed, during which over 250 mechanical tests were run and approximately 60,000 lb. of metal converted into usable castings, a specification was drawn up to cover a secondary alloy to be referred to hereafter in this paper as alloy No. 18. The chemical and mechanical limits are given in Table 2. Consideration was given during these tests to the most rapid production methods possible, utilizing a minimum amount of heat treatment.

8. To evaluate the test results given, it is necessary to review the properties of present alloys used by the company. These are listed in Table 3. It should be realized that for equipment manufactured by the Sperry Company, it is important not to permanently deform a casting during service. This deformation is limited only by the yield strength of the material, whereas ultimate breakage is a factor of the tensile strength. It will be noted from Table 3 that alloys Nos. 11 and 12 have low yield strengths.

Table 3

CASTING ALLOYS USED

Alloy	*Alcoa Number*	*Yield Strength, lb. per sq. in.*	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*
		Minimum Values		
2*		17,000	25,000	1.0
11	45	not req'd.	19,000	1.5
12	43	not req'd.	17,000	3.0
14	356T6	20,000	30,000	3.0
		Typical Values		
2 (as cast)		20,000	33,000	2.5
2 (as stress rel. at 450°F. for 5 hours)		18,000	33,000	2.5
11	45	10,000	21,000	5.0
12	43	8,000	20,000	7.0
14	356T6	23,000	33,000	4.5

ANALYSIS OF HEATS

9. To cover the range of properties to be expected, two series of heats have been selected for complete detailed presentation. Heat 40L represents the low end of the composition range expected, covering both major elements and impurities. Heat 40M represents low impurities with average copper and silicon. Heat 40K covers average copper and silicon with high impurities, and 40D represents a heat containing excessively high magnesium. Table 1 gives the analyses of these heats.

* A Sperry alloy—17 per cent zinc, 3 per cent copper, remainder aluminum.

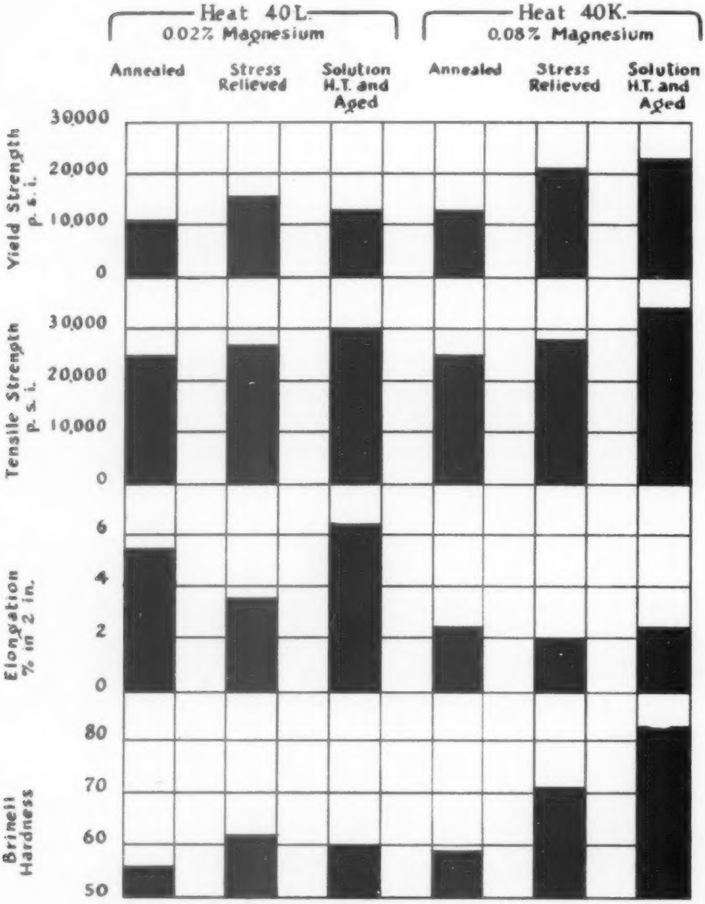


FIG. 1—EFFECT OF HEAT TREATMENT ON ALLOY NO. 18.

10. Secondary aluminum alloys, in general, as-cast, have quite low elongations. Typical values in this respect as-cast and one week old are 2 per cent. This may be detrimental in straightening of castings prior to machining, resulting in some cracks, or at least straining the casting to a point where it might be endangered during its service life. A further objection to a strained casting is the tendency to distort during machining operations.

11. A large number of the alloys now in use, particularly alloy No. 14 and the secondary alloy, contain age hardening constituents. These result in changing physical properties and may affect dimen-

sions over a long period of time following casting. Stress relieving, or solution heat treating and artificial aging, satisfactorily prevent this condition. It is necessary to take reasonable precautions in the use of a new material and the possibilities of using heat treatment in this respect have been carefully considered. The results of this investigation are shown graphically in Fig. 1.

Heat Treatments

12. The possible heat treatments which may be applied consist of annealing, stress relieving, or full solution heat treatment and artificial aging. Figure 1 shows results obtained for the extreme ranges of analyses utilizing these three treatments. The cycles used are shown in Table 4. The yield strength, tensile strength, elongation, and hardness are markedly affected by these three treatments. Annealing, regardless of analysis, tends to result in low yield strength, low hardness, and also tends to lower the tensile strength and increase the elongation. The tendency toward raising the elongation is only perceptible with low impurities. By comparison, both stress relieving and solution heat treating and artificial aging result in higher yield strength, tensile strength, and hardness, and only slightly lower elongation in the case of the stress relieving.

Table 4

HEAT TREATMENTS USED

Treatment	*Temp.°F.*	*Time, hrs.*	
Annealing	750	1	Air Cooled
Stress Relieving	450	5	Air Cooled
Solution H. T. and Artificial Aging	950	15	Water Quench
followed by	320	3	Air Cooled

13. It has been proved that stress relieving satisfactorily relieves casting and cold working stresses and also eliminates the possibility of further age hardening due to precipitation.

14. In Sperry equipment, a reasonably high yield point is a basic requirement, and it is believed that 15,000 p.s.i. is a reasonable minimum figure. This is 75 per cent of that obtained on alloy No. 14, twice that obtained with alloy No. 12, and 50 per cent higher than alloy No. 11. Sperry alloy No. 2, which has been considered satisfactory for many years, in the stress relieved condition, results in a yield point of approximately 18,000 p.s.i., which is an average

figure. Referring again to Fig. 1, it can be seen that, regardless of composition, a 15,000 p.s.i. minimum yield strength can be achieved by the use of a stress relieving treatment and that other properties appear satisfactory. It is also evident that if the solution treatment and artificial aging procedure were to be used, more specific control of the magnesium content would be required, resulting in more difficult operation, particularly in sub-contractors' foundries.

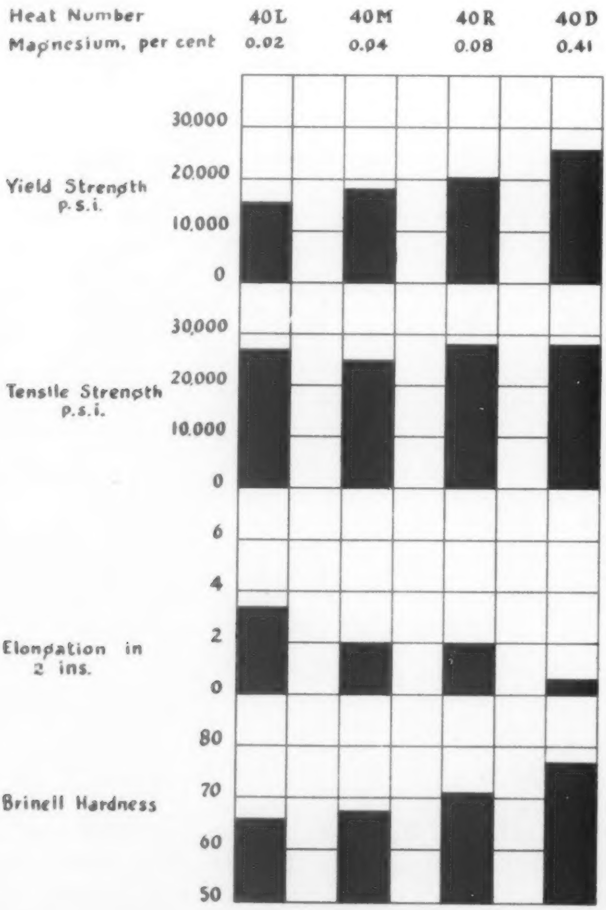


FIG. 2—EFFECT OF MAGNESIUM CONTENT ON THE PROPERTIES DEVELOPED BY ALLOY No. 18 AFTER BEING CAST AND STRESS RELIEVED AT 450°F. FOR 5 HOURS.

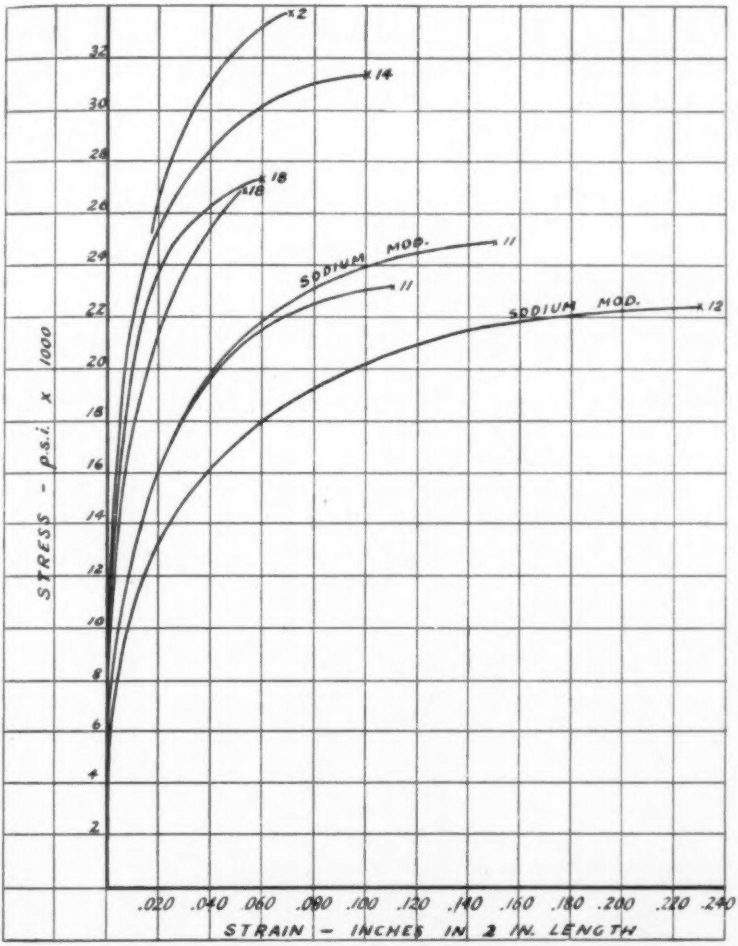


FIG. 3—STRESS-STRAIN DATA ON ALLOYS LISTED IN TABLES 2 AND 3.

Effect of Magnesium

15. Consequently specific attention was paid to stress relieved properties. Figure 2 presents this graphically in connection with the effect of magnesium. It should be pointed out that the last column, heat 40D, is outside the limits of our proposed specification. It will be seen from this chart that throughout the range of analyses which we intend to employ, satisfactory physical properties can be obtained.

Stress-Strain Data

16. Figure 3 gives the stress-strain data on all the aluminum alloys investigated up to the breaking point. It will be noticed that the straight silicon alloys show higher elongations and lower strengths than alloys Nos. 2, 14, and 18. We are, however, more interested in the portions of the curve representing elastic deflection. This section of Fig. 3 has been enlarged to form Fig. 4. The alloy No. 14 curve is the highest of the group. The alloy No. 2

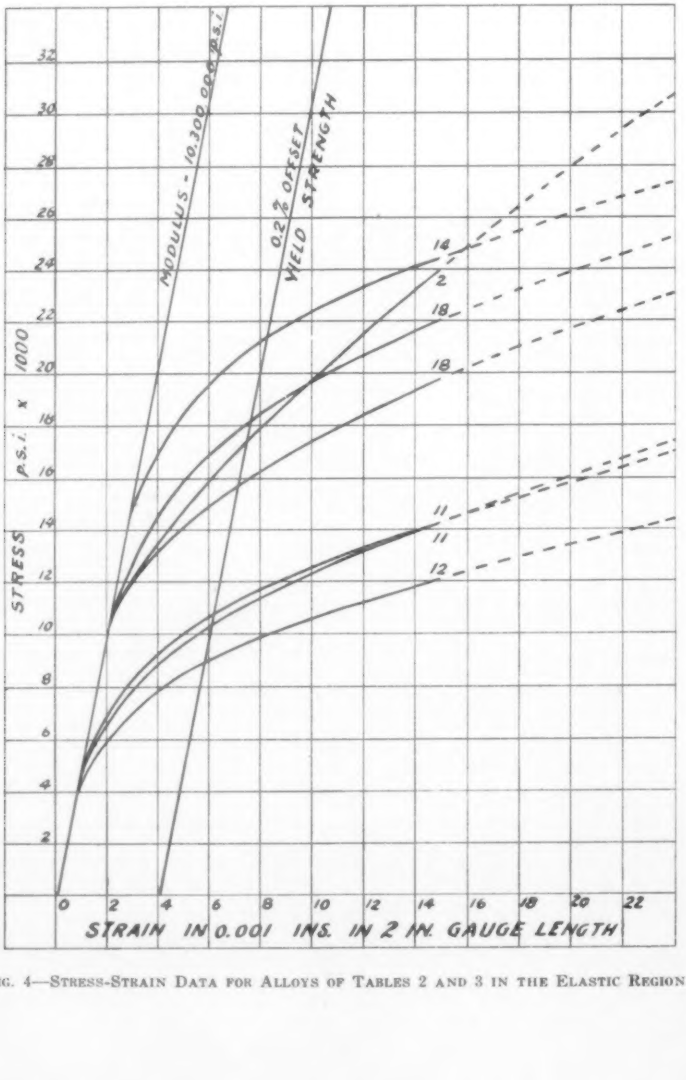


FIG. 4—STRESS-STRAIN DATA FOR ALLOYS OF TABLES 2 AND 3 IN THE ELASTIC REGION.

curve falls between two curves representing average and minimum results on the new alloy No. 18, whereas the silicon alloys Nos. 11 and 12 fall below this range. This would tend to indicate that the elastic properties of the new secondary alloy will be as satisfactory as those of our present alloy No. 2. Curves for both alloys represent the stress relieved condition.

Other Properties

17. On the basis of the castings which were made, satisfactory foundry properties in the range covered by our analysis are assured. Machinability appears satisfactory so far as can be learned from the castings which have been processed. There has been insufficient time to complete tests on the shock resistance of this material.

18. Alloy No. 18 anodizes very well by both sulfuric acid and chromic acid processes. Salt spray testing is, at the time of the writing of this paper, incomplete. However, samples anodized by both sulfuric and chromic acid methods show no signs of corrosion in 20 per cent salt spray after 720 hours in the case of the sulfuric acid process, and 300 hours in the case of the chromic acid process.

Air-Hardening Properties

19. It was found that alloy No. 18 air-hardens after casting, the degree of air-hardening being greater the higher the magnesium content. This air-hardening adversely affects the ability of a casting to stand straightening, and, as a result, straightening must be done before much air-hardening has occurred. In the range of 0.01 to 0.10 per cent magnesium, this means before the casting has aged one week.

20. Table 5 shows the effect of air-hardening on the mechanical properties of material having 0.01 to 0.10 per cent magnesium. It also gives a comparison of various air-hardening properties and those obtained by heat treatment for 1 hour at 750°F. and for 5 hours at 450°F. It will be noted in the chemical analysis of heat 40Q (the material having 0.01 per cent magnesium) that the copper is 4.12 per cent and the silicon is 2.15 per cent. A rather complete investigation of material having these copper and silicon contents has been carried out, the results of which are not given in detail in this paper. The results of heat 40Q are presented because this heat has the lowest magnesium content of any secondary metal investigated.

Table 5

EFFECT OF MAGNESIUM ON AIR-HARDENING PROPERTIES

Heat No.	*Treatment*	*Yield Strength, lb. per sq. in.*	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*	*Brinell Hardness No.*
40 P	1 day old	13,810	26,890	2.5	62
		15,780	26,490	2.5	63
40 P	1 week old	18,300	28,820	2.5	71
		18,600	27,650	2.5	72
40 P	2 weeks old	18,480	28,710	2.5	72
		18,080	28,740	2.5	74
40 P	1 month old	20,480	25,350	1.5	73
		18,800	27,570	2.0	74
40 P	4 hours at 450° F.	20,970	29,500	1.5	75
		22,430	29,250	1.5	77
40 P	1 hour at 750°F.	11,270	25,560	3.0	61
		11,950	24,130	2.5	62
40 Q	1 day old	12,830	25,650	4.0	60
		12,030	25,310	3.5	60
40 Q	1 week old	12,880	26,500	3.0	65
		14,360	26,500	3.0	65
40 Q	2 weeks old	16,000	23,950	2.5	66
		15,660	26,750	3.0	66
40 Q	1 month old	16,540	27,570	2.5	68
		17,130	27,416	2.5	67
40 Q	5 hours at 450°F.	16,870	27,230	2.0	65
		18,230	27,720	2.5	67
40 Q	1 hour at 750°F.	11,130	22,740	3.0	58
		11,930	25,360	4.0	60

Microstructure

21. The microstructure of alloy No. 18 was examined to determine if any correlation could be found between microstructure and mechanical properties.

22. Figure 5, at 100x, shows the microstructure of a test bar of heat 40K, two weeks old. This is the typical structure of alloy No. 18. Room temperature aging or heat treatment at 450°F. has no effect on this microstructure.

23. Figure 6, at 100x, shows the microstructure of a test bar of heat 40B containing 0.16 per cent magnesium. This needle-like structure has been noted on the examination of several brittle castings that have broken in straightening. All of these castings contained magnesium in excess of 0.10 per cent.

24. Figure 7, at 500x, is the same as in Fig. 6. This shows that the needle-like structure is caused by the presence of narrow plates, the composition of which is unknown to the writer.

25. Figure 8, at 500x, shows alpha-iron-aluminum-silicide scrip

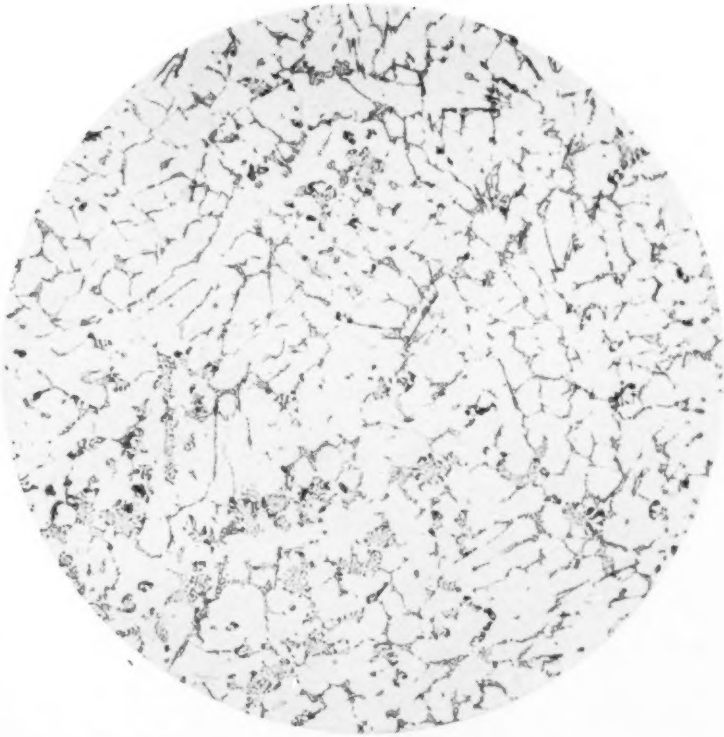


FIG. 5—MICROSTRUCTURE OF HEAT 40K, TWO WEEKS OLD, 100x.

present in heat 40D. The presence of a large amount of this material lowers the ductility of the metal but to a lesser extent than results from the presence of the needle-like structure caused by excessive magnesium content.

CONCLUSIONS

26. It has been found that, with proper foundry technique and care, satisfactory castings can be produced from alloy No. 18 having a basic composition of 3 per cent copper, 4 per cent silicon and 0.10 per cent maximum magnesium. An alloy having a basic composition of 4 per cent copper, 2 per cent silicon and 0.10 per cent maximum magnesium is much more available in the market, has nearly the same mechanical properties and foundry characteristics, but does not lend itself so well to the casting of exceedingly intricate parts.

27. The most important mechanical property to be considered in changing from a primary alloy to a secondary alloy is yield strength, and every effort should be made to evaluate yield strength in physical testing of secondary alloys.

28. A minimum elongation of 1.5 per cent has been found to be essential in the production of useful castings. This is predicated on what is required of the metal in use, rather than on what can be easily obtained from the metal in the foundry.

29. The T6, or high temperature solution heat treatment, is not recommended for the copper-silicon type secondary metal. This type of heat treatment will give great variations in mechanical properties as the result of the large variation in the amount of impurities that may be present. A simple heat treatment of 5 hours at 450°F., followed by cooling in still air, is recommended as the best possible heat treatment for this alloy. This treatment will con-

FIG. 6—MICROSTRUCTURE OF HEAT 40B CONTAINING 0.16 PER CENT MAGNESIUM, 100x.

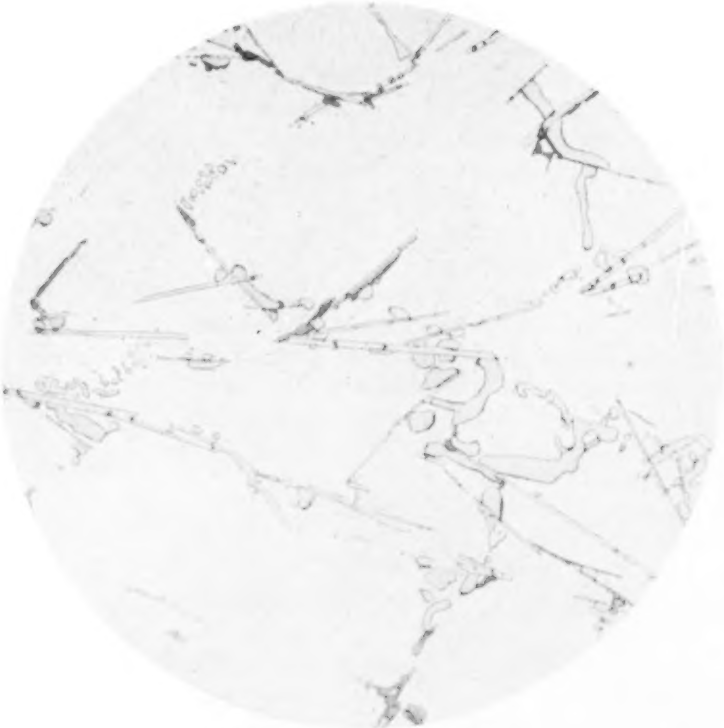


FIG. 7—SAME AS FIG. 6, BUT AT 500x.

sistently result in a yield strength of over 15,000 p.s.i. and will give much less variation in mechanical properties as affected by impurities present.

CHANGE-OVER DIFFICULTIES

30. There are many difficulties to be overcome in the foundry when changing from primary alloys to secondary alloys of the copper-silicon type. They are listed as follows:

(A) *Dross and Oxide Inclusions*

Secondary aluminum may contain more oxides than primary metal. The effects of these oxides, namely, lower ductility, can be kept to a minimum by the use of proper fluxes in melting. Any of a number of commercial fluxes will do. All gates and risers must be remelted and cast into ingots before being reused.

(B) Magnesium Contamination

Magnesium is the most harmful impurity present in alloy No. 18. The top limit has been set at 0.10 per cent. This is the absolute top limit that can be tolerated, and every effort must be exercised to prevent the contamination of alloy No. 18 with other magnesium bearing alloys. The remelt ingot must be analyzed for magnesium.

(C) Increased Shrinkage

Alloy No. 18 shows a greater tendency to shrink from the liquid to the solid than do the silicon alloys. Risers and chills are very effective with this alloy and must be used in greater abundance. Great care must be used in changing to alloy No. 18 to see that enough additional risers are used to produce solid castings.

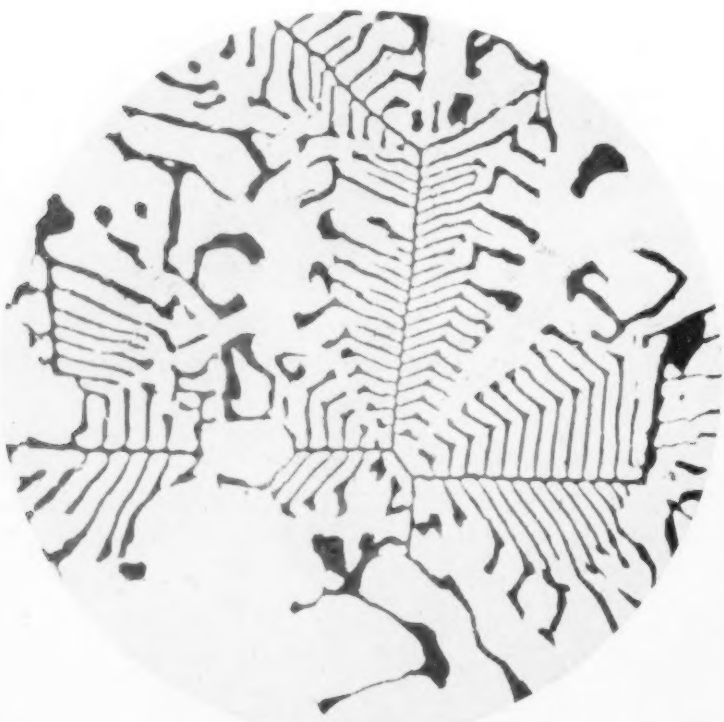


FIG. 8—MICROGRAPH SHOWING THE ALPHA-IRON-ALUMINUM-SILICIDE PRESENT IN HEAT 40D. 500x.

(*D*) *Grain Coarsening*

Alloy No. 18, like many other aluminum alloys, is subject to grain coarsening when poured at high temperatures, which in turn results in lower ductility. As alloy No. 18 has very little ductility when properly made, every care must be taken not to overheat the metal and to use such gating as to make possible the pouring of the castings at the lowest possible temperature. Good results have been obtained by not exceeding 1350°F.

(*E*) *Low Ductility As Affecting Straightening*

Castings of alloy No. 18 can be properly straightened. However, this alloy air-hardens for about a month after casting. In a month, the yield strength will increase from about 12,000 p.s.i., as-cast, to about 20,000 p.s.i.; and the hardness will increase from about 60 to 70 Brinell. Most of this hardening occurs in the first week. Therefore, castings should be straightened as soon as possible after pouring. After straightening, castings should be stress relieved for 5 hours at 450°F. This causes the alloy to become fully hardened and relieves stresses due to straightening. Castings cannot well be straightened after this heat treatment. Every effort must be made to have the castings properly straightened before they are heat treated; otherwise, if straightening is required at the time of machining, many cracked castings will result.

CONTROL OF SECONDARY MATERIAL

31. Remember that so-called "secondary" does not mean "pots and pans." It is an alloy which is a compromise between many factors, chiefly availability and mechanical properties. As such, it must be treated with respect and more carefully handled than primary materials. Therefore, these are the important points:

(A) Analysis must be controlled.
(B) Melting practice must be better than average.
(C) Molding should be liberal in use of risers and chills.
(D) Straightening must be carefully and completely done as soon as possible after removal from the sand.
(E) To insure satisfactory performance, castings must be stress relieved but cannot be straightened after this treatment.

32. The difficulties encountered in the foundry in the use of secondary alloy, as listed above, should be given every consideration

by the designer of parts to be cast from this alloy. Every effort should be made to design parts requiring a minimum amount of straightening or bending in fabrication and use.

ACKNOWLEDGMENTS

33. The writer wishes to express deep appreciation to the members of the Sperry Materials Laboratory and Foundry for help and guidance in this work, especially to R. W. Waring for direction, to W. M. Jung for micrographs, to W. C. Spiess for anodizing tests, to D. M. Kendall for physical tests, and to A. Schlagenhauf and W. A. Cabre for fullest foundry cooperation.

DISCUSSION

Presiding: W. J. LAIRD, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Co-Chairman: WM. ROMANOFF, H. Kramer & Co., Chicago, Ill.

CHAIRMAN LAIRD: The most striking thing that occurred to me in connection with the possibilities of wider application of secondary aluminum to war castings was concern about what strides we are making in having government specifications altered from a chemistry standpoint. Despite the fact that we may be able to obtain and exceed certain minimum physical properties, the properties demanded are such that the application of secondary aluminum to war goods must be accompanied by the alteration of the chemistry of the specifications. Can you give us any information along that line?

MR. MARTIN: We can refer you to the chemical specification that we have given in the paper, namely, copper 2.25 to 3.50 per cent, silicon 3.25 to 4.50 per cent, iron 0.9 per cent max., manganese and zinc 0.6 per cent max., nickel 0.5 per cent max., and magnesium 0.10 per cent max. This is quite an open range, and we feel that zinc is the least harmful of all impurities. Heretofore, it has been limited to 0.03 per cent in most government specifications. As pointed out in the paper, magnesium is most harmful and must be kept under 0.10 per cent.

The Navy has added an A specification to each class of their 46A1 sand cast specification, so we now have a class 2A, 3A and 4A in which the major elements remain the same, and the impurities are listed as being of the same order as in our alloy No. 18 specification. Two per cent copper max. has been added to the class 3A material of 7 per cent silicon and 0.3 per cent magnesium. It is necessary that any secondary alloy contain not less than 2 per cent copper because so much scrap is copper bearing.

D. V. LUDWIG[1]: At a conference between Navy officials and foundrymen, it was decided to use 4A which is the 195 type of alloy, unheat-

[1] Capitol Foundry Corp., Long Island City, N. Y.

treated. In type 4A alloy, the silicon has been raised to 2 per cent to make it obtainable. The copper has been dropped to as low as 3.50 per cent. The zinc has been raised to 1 per cent, the iron to 9 per cent, the manganese to 0.6 per cent and the magnesium has been limited to 0.1 per cent. Magnesium is considered the most critical element involved.

MEMBER: Can the 4A unheat-treated alloy be substituted for 195 in all cases?

MR. LUDWIG: In all cases, except aircraft. It is ship-board material. The possibility of substitution throughout on all specifications is being considered.

MEMBER: What are the particular characteristics of the 17 per cent zinc alloy, and how do the smelters reduce the magnesium from 1 to 0.1 per cent?

MR. MARTIN: The 17 per cent zinc alloy is a high strength alloy that requires no heat treatment to improve the physical properties. This alloy, when properly made, will have, in the cast condition, a yield strength of from 20,000 to 30,000 lb. per sq. in., and a tensile strength of from 30,000 to 40,000 lb. per sq. in., with a spread of at least 10,000 lb. per sq. in. between yield and tensile strength. It has better foundry characteristics than the 4.50 per cent copper alloy, and the best machinability of any cast aluminum that has ever been used by our company. When properly anodized, its corrosion resistance is satisfactory. Its drawbacks are that it becomes very brittle if magnesium exceeds 0.05 per cent, or it becomes very hot short if lead exceeds 0.05 per cent.

We do not know how the magnesium is removed by the secondary smelters.

MR. LUDWIG: The smelters use chlorine for the removal of magnesium.

MEMBER: It seems to me that we may have a considerable source of supply of the alloy of Federal specification 591, and it may be the only material available for certain classes of work.

MR. MARTIN: Specification 591 is one being drawn up to allow from about 2 to 5 per cent copper and 2 to 5 per cent silicon. This would permit the foundry to use either an alloy of our No. 18 type or the Navy class 4A type. It is not the intention of the author of this specification that any chemical composition within these limits will meet the required physicals. There is objection to this type of a specification on the basis that the foundry might not know this and, as a result, make a great many castings that are not usable. A better specification of this type is the one drawn up by the Frankfort Arsenal which requires no chemical limits but gives limiting physical requirements.

MEMBER: What effect will the 2 per cent copper have on the 356 metal?

MR. MARTIN: We found that if it were heat treated with Alcoa 356, *i.e.*, Navy class No. 3 material, it would be completely burned. By using a solution temperature of around 930°F., we obtained a product with around 33,000 lb. per sq. in. tensile strength and some elongation right after quenching, that is, in the T4 condition. However, after artificial aging at 320°F. for three hours, *i.e.*, the T6 heat treatment, we got

about 40,000 lb. per sq. in. yield strength and 40,000 lb. per sq. in. ultimate strength with no elongation. This is a very brittle condition and should be avoided. Leaving it in the T4 condition is not the solution to the problem because the metal will eventually acquire T6 properties by room temperature aging and, at the same time, do a certain amount of distorting.

MEMBER: Have you experimented with secondary aluminum in conformance with specification 355, 0.4 to 0.6 per cent magnesium?

MR. MARTIN: Alcoa 355 and Alcoa 356 are very much alike. The only work we have done has been on the alloy mentioned before. We have been advised by the Aluminum Conservation Section and the Aluminum and Magnesium Division of the W.P.B. that there is no point in using secondary silicon alloys as these alloys, even when made from scrap, can hardly be classified as secondary metal at this time.

D. L. LONGEUVILLE[2]: How much consideration was given to temperature in pouring the castings which cracked in straightening, due to the magnesium content?

MR. MARTIN: They were melted under good control and poured at 1250°F. That is not the only case where this alloy with high magnesium has caused cracking in straightening. The magnesium drops the elongation to about 0.5 per cent, and it is not possible to consistently straighten castings with so little ductility.

MR. LONGEUVILLE: What about the zinc content?

MR. MARTIN: We think zinc is harmless up to about 17 per cent and believe the limit is that amount which will introduce hot shortness. This apparently is quite high.

[2] Wright Aeronautical Corp., Cincinnati, O.

Report of the Subcommittee on Sintering Test, Foundry Sand Research Committee, 1941-1942

By J. B. Caine*, Lockland, Ohio

The work of the Subcommittee on Sintering Test, Foundry Sand Research Committee during the past year has been not only a continuation of the previous work of standardizing the test itself, but also some work has been done in correlating the test with the behavior of the sand in the foundry. During the year 1940-1941, the prime interest of the committee was in standardizing the test. The results of this standardization and the changes in the procedure for making this test have been reported to the Association in a progress report[1].

These changes in the procedure may be summarized briefly as follows: The load on the specimen and the time element, especially on cooling, have been specified exactly, as these two variables are shown to have an effect on the sintering points, especially the "*A*" point. Definite end-points have been established for determining the sintering points, to eliminate the human variable in determining when the sand has "burned fast" to the ribbon, as was specified in the previous procedure. This point has been the main reason for the variations in the sintering point that have been reported on the same sand in the past.

Suggested Improvements in Apparatus

Two improvements in the sintering apparatus have been suggested this year. When testing sand containing combustible material, if smoke is generated, it can interfere with the optical py-

* Metallurgist, Sawbrook Steel Casting Co. and Chairman, A.F.A. Foundry Sand Research Sintering Test Subcommittee.

1 *Progress Report of Sintering Test Subcommittee, Foundry Sand Research Committee*, Transactions, American Foundrymen's Association, vol. 49, pp. 552-558 (1941).

Note: This report was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

rometer readings, giving false low temperatures. The newer apparatus on the market is ventilated. Some provision for ventilation should be made in the older types if the sand being tested generates much smoke. Simply leaving the door open in the older models works fairly well if no direct light falls on the platinum ribbon.

Last year, it was found that bending the braided copper leads to the ribbon holder can vary the load on the specimen and cause a variation in the sintering points, especially the "*A*" point. If a little care is taken to keep these leads straight, no difficulty will be encountered. However, much smaller and more flexible leads can be used and still carry all the current required, such as ordinary extension cord wire with the insulation removed. With these smaller leads, it is impossible for the leads to change the load on the specimen and all that is necessary is to be sure that the ribbon is centered on the sand specimen.

New Work

Last year, three simple bentonite-silica sand mixes were sent to subcommittee members for standardization. The "*A*" and "*B*" points reported, all checked, except in one case, to within plus or minus 25°F. One member reported "*A*" points 100 to 200°F. lower than the others. The reason for this variation was found, on later investigation, to be due to a variation in ribbon thickness, so the ribbon dimensions have been standardized as 3/8 x 2 x 0.002-in.

This year three more sands were sent to subcommittee members for further standardization. These sands were (1) a typical steel facing sand, (2) a typical iron sand and (3) a non-ferrous sand. These sands were selected not only to represent the three branches of the foundry industry, but also for their difficulty.

These sands show all the difficulties that were encountered in the sintering point investigations last year. For example, it is very difficult to determine the "*A*" point of this particular steel sand by the "V" method, as this sand is very friable after heating. The iron sand has such a high retained strength after heating that the "*B*" point cannot be determined by the scraper method, but must be determined by visual examination. Even with all these difficulties, the subcommittee is able to check the sintering points of these sands to within plus or minus 25 to 45°F. in all but one case, as shown in Table 1.

Table 1

SINTERING POINTS DETERMINED ON SAME SAND BY DIFFERENT LABORATORIES

	Steel Facing Sand		*Iron Sand*		*Non-Ferrous Sand*	
	"A" point, °F.	*"B" point, °F.*	*"A" point, °F.*	*"B" point, °F.*	*"A" point, °F.*	*"B" point, °F.*
Griffin Wheel Co., K. J. Jacobson	2300	2925	2250	2475	2050	2250
Hougland & Hardy, Inc., L. B. Osborn	2300	2935	2250	None	2100	2275
Bureau of Standards, C. M. Saeger, Jr.	2250	——	2060	——	2010	——
Naval Research Laboratory, H. F. Taylor	2300	2900	2050	2400	None	2200
Sawbrook Steel Casting Co., J. B. Caine	2250	2875	2100	2450	2050	2250
Average	2275±25°	2900±30°	2140±100°	2450±35°	2050±45°	2250±35°

Mr. Saeger also checked the "*A*" points of these sands using a thinner platinum ribbon ½ x 2 x 0.001-in. with the following results:

Steel Facing Sand	*Iron Sand*	*Non-Ferrous Sand*
2060°F.	1925°F.	1970°F.

As can be seen by comparing these results with those in Table 1 using the 0.002-in. thick ribbon, decreasing the ribbon thickness from 0.002 to 0.001-in. lowers the "*A*" sintering point from 80° to 215°F. *This point exemplifies the extreme care that must be taken in all the details of the test if reproducible results are to be obtained. This point cannot be emphasized too strongly,* as we can never hope to establish definite melting and sintering points for any system involving silica, because there appear to be none. All we can hope to do is to establish more or less arbitrary points that can be duplicated and that can be correlated with the behavior of the sand in the foundry.

Reasons for Reporting Two Sintering Points

This last point expresses an underlying thought that runs throughout this work. Just what does the sintering test tell us about the behavior of the sand when it comes in contact with molten metal. This thought is the reason for incorporating two sintering

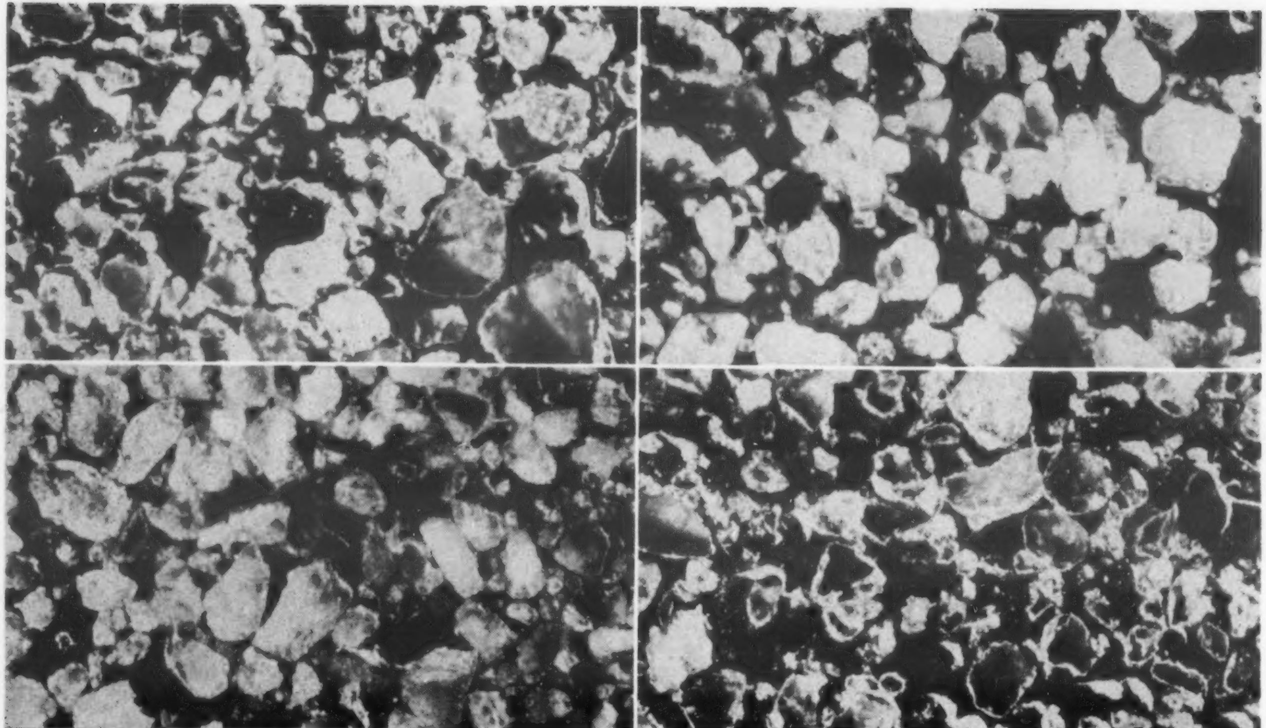


FIG. 1—TOP LEFT—SAND AS RAMMED. NO HEAT HAS BEEN APPLIED TO THIS SURFACE. x25, OBLIQUE ILLUMINATION. FIG. 2—TOP RIGHT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2200°F., x25, OBLIQUE ILLUMINATION. ONE (1) PASS OF SCRAPER REQUIRED TO REMOVE SAND. FIG. 3—BOTTOM LEFT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2300°F., x25, OBLIQUE ILLUMINATION. ONE (1) PASS OF SCRAPER REQUIRED TO REMOVE SAND. FIG. 4—BOTTOM RIGHT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2400°F., "A" SINTERING POINT. x25, OBLIQUE ILLUMINATION. ONE (1) PASS OF SCRAPER REQUIRED TO REMOVE SAND.

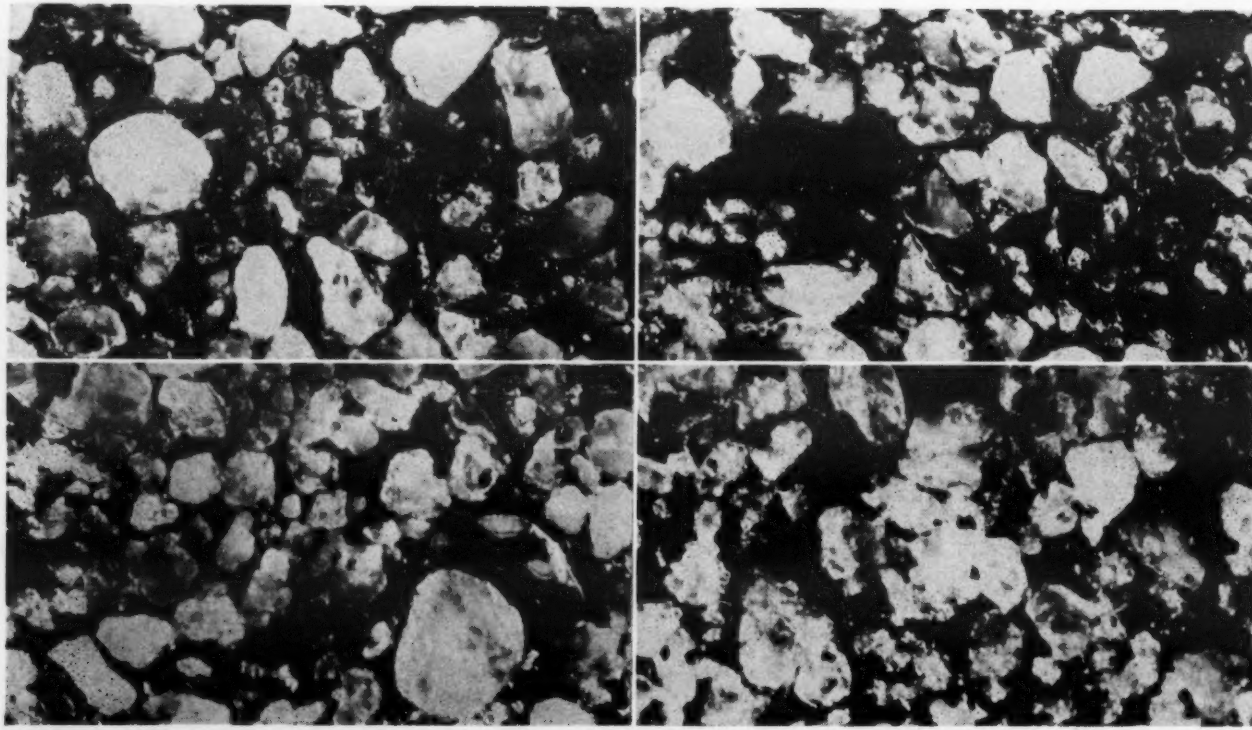


FIG. 5—TOP LEFT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2500°F., x25, OBLIQUE ILLUMINATION. TWO (2) PASSES REQUIRED TO REMOVE SAND. FIG. 6—TOP RIGHT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2600°F., x25, OBLIQUE ILLUMINATION. FIVE (5) PASSES REQUIRED TO REMOVE SAND. FIG. 7—BOTTOM LEFT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2700°F., x25, OBLIQUE ILLUMINATION. TWELVE (12) PASSES REQUIRED TO REMOVE SAND. FIG. 8—BOTTOM RIGHT—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2800°F., x25, OBLIQUE ILLUMINATION. "B" POINT 2850°F. TWENTY (20) PASSES REQUIRED TO REMOVE SAND.

points in the revised procedure, instead of one as in the earlier procedure. Some of the members of the subcommittee, especially those in the west, claimed that the low temperature "*A*" point, when the sand just starts to stick to the ribbon under very carefully controlled conditions, did not give the information that they required. This point occurs at temperatures lower than the pouring temperatures of iron and steel.

They proposed another point, or "*B*" point, that is the temperature when the smaller grains can be seen to start to fuse at low magnifications. Then, to eliminate the human variable in any visual examination, this point was correlated with the amount of work required to remove the sand from the platinum ribbon. It was found that it requires 50 passes of a scraper under a 4 oz. load to remove the sand from the ribbon at this temperature. Details regarding these procedures can be found in last year's report[1] of the subcommittee.

Investigation of Meaning of Sintering Points

These points were called the "*A*" and "*B*" points not only to avoid confusion, but also because no one was sure as to just what was occurring at these points. In an effort to find out, a sand was heated under the platinum ribbon for 4 min., as specified in the sintering test procedure, increasing the temperature each time 100°F. from 2200° to 3000°F. The ribbon then was stripped from the sand specimen and the surface examined at x25.

After cooling, the sand was saturated with "Bakelite Resenoid" so that it could be polished and examined. The photomicrographs, shown in Figs. 1 to 10, illustrate what is happening to the sand. The sand is the steel facing sand similar to sand No. 1, the base sand of which is a crude Ohio sand containing 97 per cent silica and with an A.F.A. fineness number of 56. Two per cent bentonite has been added. The green permeability is 160. The "*A*" sintering point was found to be 2400°F., the "*B*" point 2850°. Oblique illumination is used in Figs. 1 to 10 inclusive, so the sand grains are light, the voids dark.

Figure 1 shows the sand as rammed. No heat has been applied to this surface. Figure 2 shows the surface in contact with the platinum ribbon for 4 min. at 2200°F. There is little difference between this surface and the as-rammed surface shown in Fig. 1. The same is true of Figs. 3, 4, 5, 6, and 7, of the sand at 2300°, 2400°, 2500°, 2600° and 2700°F., although we have gone through

the "*A*" point at 2400°F. The only change, if any, is a slight rounding of the corners of the smaller grains as the temperature is increased.

At 2800°F., as shown in Fig. 8, a few of the smaller grains can be seen to have started to fuse onto the larger ones. At 2900°F.,

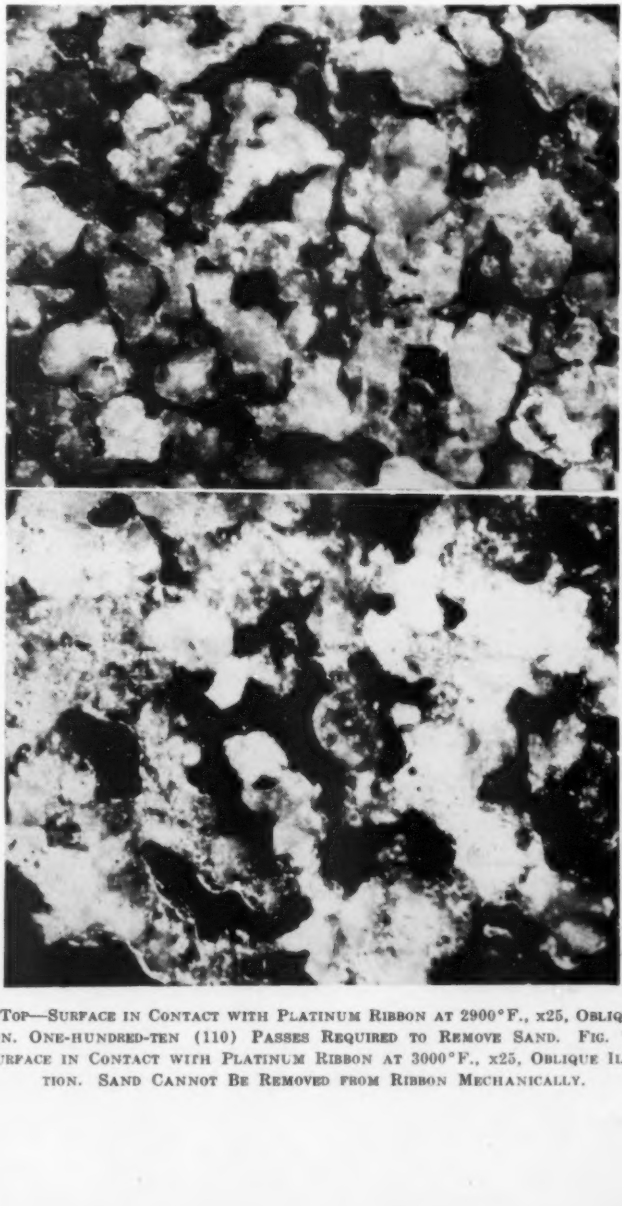


FIG. 9—TOP—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 2900°F., x25, OBLIQUE ILLUMINATION. ONE-HUNDRED-TEN (110) PASSES REQUIRED TO REMOVE SAND. FIG. 10—BOTTOM—SURFACE IN CONTACT WITH PLATINUM RIBBON AT 3000°F., x25, OBLIQUE ILLUMINATION. SAND CANNOT BE REMOVED FROM RIBBON MECHANICALLY.

in Fig. 9, at least half of the grains have fused and run together, and finally at 3000°F., in Fig. 10, the surface of the sand is completely molten and no individual grains can be seen. The "*B*" point of this sand as determined when 50 passes of the scraper are required to remove the sand from the ribbon is 2850°F.

Explanation of Behavior

It would seem from these photomicrographs that no change has occurred in the sand grains as units until temperatures much above the "*A*" sintering point are reached. This is logical if one considers each individual sand grain to be heterogeneous. The center core is composed of practically pure silica with a high sintering point, and this core is coated with a material that not only has a lower sintering and melting point, but is almost always able to flux the silica forming silicates that have even lower melting and softening points than the two original components.

The "*A*" sintering point then is the point where the coating on the sand grain has sintered and softened enough to adhere to the platinum ribbon with sufficient force to bend it when it is lifted. The sand grain as a whole has not been changed. This point is the melting or softening point of the clay substance on the surface of the sand grains. The force required to remove the sand grains from the ribbon at this temperature is very small. They can be rubbed off the ribbon with the finger.

As the temperature is increased, there is very little change in either the appearance of the sand grains or the force required to remove the sand from the ribbon until the "*B*" point is approached. Here, definite fusion of the smaller grains as units can be seen under the microscope and the energy required to remove the sand from the ribbon increases rapidly. At temperatures slightly over the "*B*" point, the sand cannot be removed from the ribbon mechanically. The "*B*" point is then the point of incipient fusion of the sand grains as a whole. It is not a true melting point as silica melts over a wide range of as much as 400°F., depending on a number of variables.

Correlation of Sintering Point with Foundry Practice

In an effort to see if the sintering points can be correlated with the behavior of the sand when it comes in contact with molten metal, standard 2-in. round A.F.A. test specimens of the three sands studied this year were rammed in a mold and the mold filled

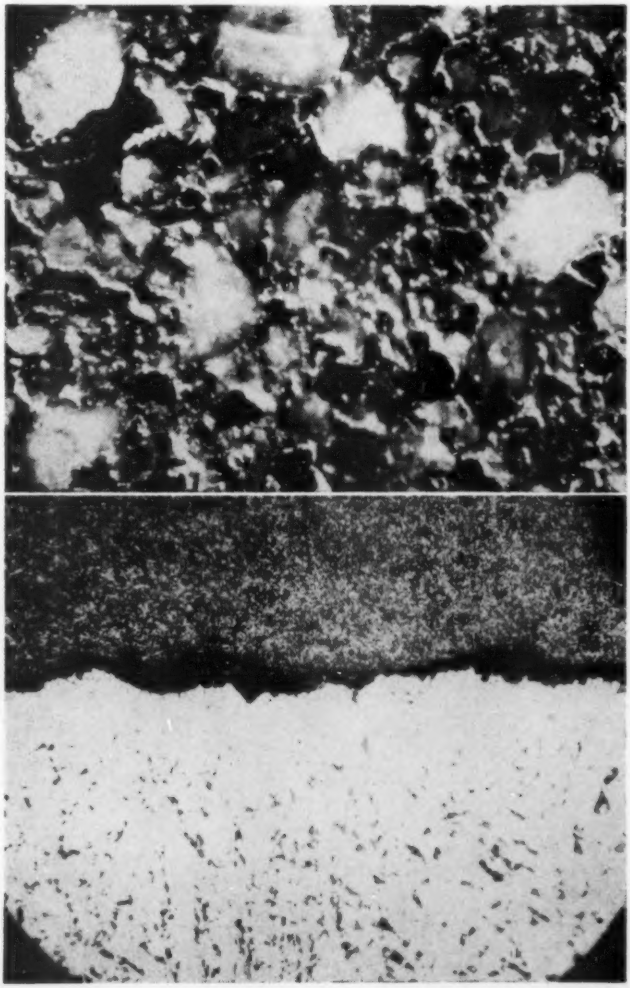


FIG. 11—TOP—SURFACE OF STEEL SAND NO. 1 IN CONTACT WITH MOLTEN STEEL AT 2975°F., x25, OBLIQUE ILLUMINATION. FIG. 12—BOTTOM—SURFACE AT RIGHT ANGLES TO SAND METAL INTERFACE, STEEL SAND NO. 1, x25, VERTICAL ILLUMINATION. NO PENETRATION.

with steel at 2975°F., making a 4-in. square section. This is, of course, a much too severe test for the iron and non-ferrous sands, but gives an exaggerated picture of what occurs at high pouring temperatures and, because it is exaggerated, clearly shows what happens.

Figure 11 shows the surface at x25 of the steel facing sand in

contact with the metal at 2975°F. As can be seen, the surface of even this high sintering point sand shows a great deal of fusion. The amount of fusion lies, as it should, between the amount of fusion shown by this sand when in contact with the platinum ribbon at 2900° and 3000°F. in the sintering apparatus (Figs. 9 and 10). Note the voids between the sand grains, the dark areas, as

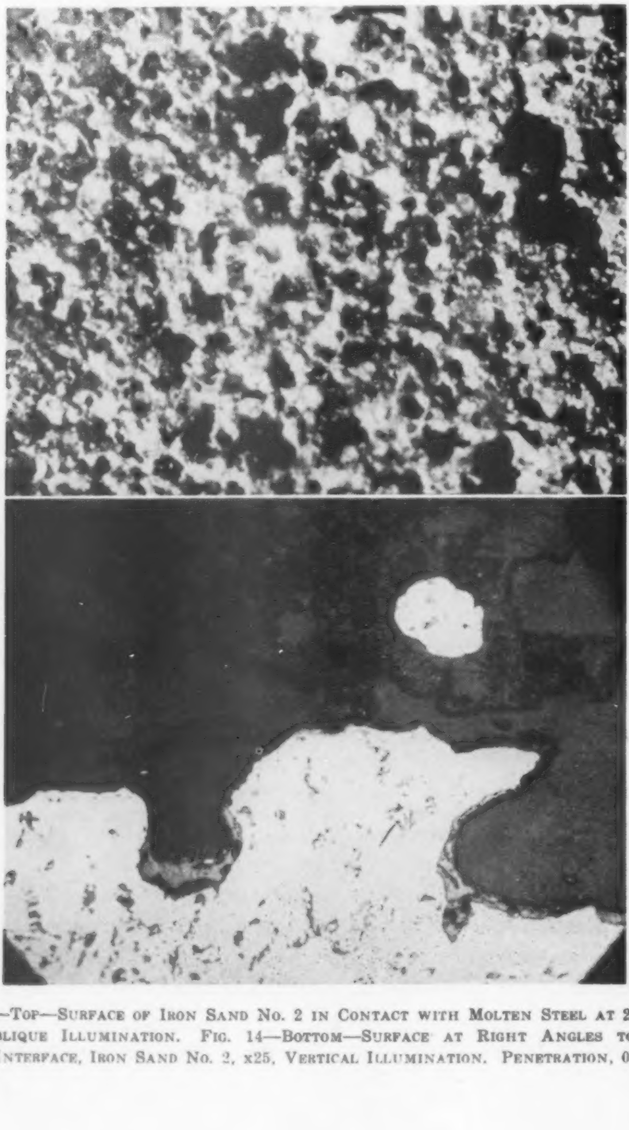


FIG. 13—TOP—SURFACE OF IRON SAND NO. 2 IN CONTACT WITH MOLTEN STEEL AT 2975°F., x25, OBLIQUE ILLUMINATION. FIG. 14—BOTTOM—SURFACE AT RIGHT ANGLES TO SAND METAL INTERFACE, IRON SAND NO. 2, x25, VERTICAL ILLUMINATION. PENETRATION, 0.064-IN.

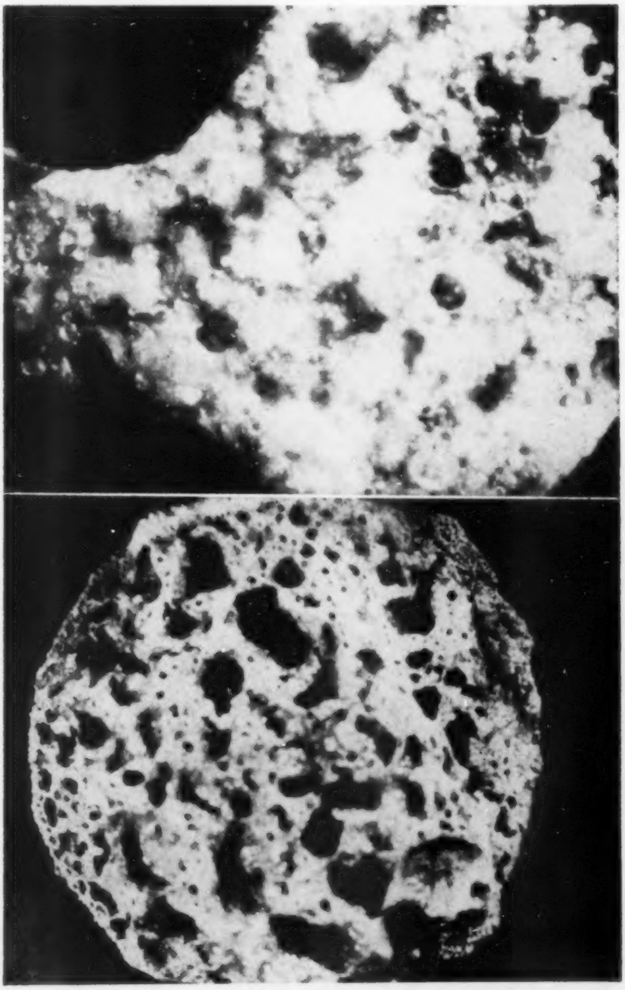


FIG. 15—TOP—SURFACE OF NON-FERROUS SAND NO. 3 IN CONTACT WITH MOLTEN STEEL AT 2975°F., x25, OBLIQUE ILLUMINATION. FIG. 16—BOTTOM—SAME SURFACE AS SHOWN IN FIG. 15, BUT AT x1.5.

we will be referring to them later. These voids are about the same size as those in the as-rammed surface in Fig. 1.

Figure 12 shows a section through the sand-metal interface of this sand. Unfortunately, the reflectivity of sand and metal are so different that the same type of illumination cannot be used for both sand and steel, so in this photomicrograph, vertical illumi-

nation must be used instead of oblique, as used in the previous photomicrographs, and the light and dark areas are reversed, the steel light, the sand dark. This sand peels perfectly from the casting on shakeout, the surface tension of the steel at this pouring temperature is high enough so that there is no penetration into the voids and the surface of the casting is fairly smooth.

Figure 13 shows the surface of the iron sand in contact with the steel at 2975°F. Although this sand is much finer than the steel sand and has a green permeability of 19, voids have started to open due to fusion. They are as large, if not larger, than those in the steel sand. Figure 14 shows the section at right angles to the sand metal interface, using vertical illumination. This sand was hard to remove from the casting. It not only fused to the surface of the steel tightly enough to cause some difficulty in cleaning, but the metal also has penetrated the voids that have opened due to fusion and has "keyed" some of the sand to the casting. This "keyed on" sand is extremely difficult to remove.

Figure 15 shows the surface of the non-ferrous sand in contact with the steel at 2975°F. The sand has fused completely, and in doing so, has opened up enormous voids, although the original permeability of this sand was only 11. This photomicrograph at x25 only shows a neck of sand in between two of these voids. To see these voids, a much lower magnification must be used, so Fig. 16 shows this same sand at x1.5. The 2-in. diameter core is simply honeycombed with voids, some of them of ¼-in. diameter.

Then, as would be expected, the metal has penetrated these voids, keying the sand onto the casting. Figures 17 and 18 show a section at right angles to the sand-metal interface, illustrating this penetration at x25 and x1.5, respectively. The sand has not only fused to the metal, but the metal has penetrated the sand as much as 3/16-in.

How Voids Open

The reason that voids do open up when sand fuses is undoubtedly the increase in specific gravity or density of fused silica or silicate when compared with a mass of individual sand grains. The non-ferrous sand has a specific gravity of 1.70, whereas fused silica has a specific gravity of 2.65. This increase in specific gravity would mean that the fused sand would only occupy 64 per cent as much space as the unfused sand, the difference, 36 per cent, can only be voids.

This matter of penetration, whether it be due to fusion or be mechanical due to too large voids present in the sand as-rammed, seems to be a major factor in the problem of "burnt on sand" in iron and steel foundries. However, there are so many other variables that enter into the picture that no definite conclusions can be drawn at present.

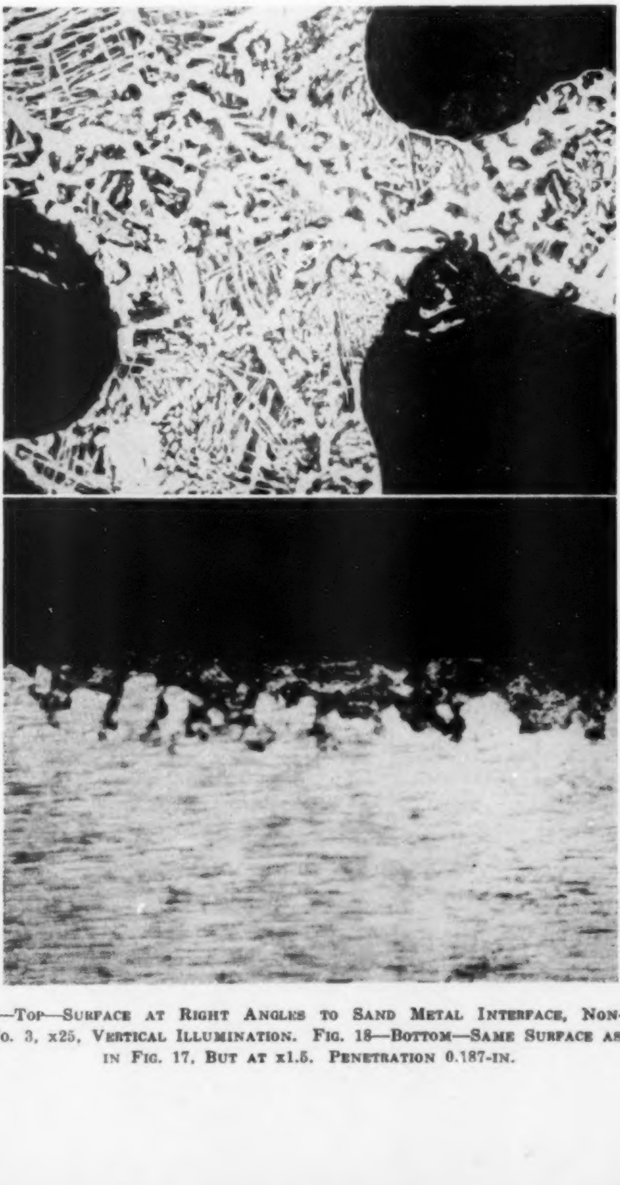


FIG. 17—TOP—SURFACE AT RIGHT ANGLES TO SAND METAL INTERFACE, NON-FERROUS SAND NO. 3, x25, VERTICAL ILLUMINATION. FIG. 18—BOTTOM—SAME SURFACE AS SHOWN IN FIG. 17, BUT AT x1.5. PENETRATION 0.187-IN.

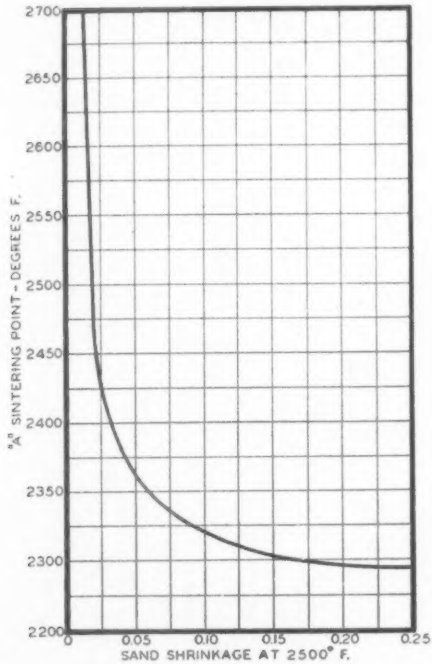


FIG. 19—SAND SHRINKAGE VERSUS "A" SINTERING POINT, ACCORDING TO DIETERT AND WOODLIFF.

Sintering Point vs. Contraction

The sintering point of a sand not only acts independently as one factor in determining how a sand peels from a casting, but also seems to affect other properties of the sand at high temperatures. Woodliff and Dietert have established a definite relation between the "*A*" sintering point and the contraction of the sand when heated to 2500°F. in the dilatometer. As can be seen from Fig. 19, the contraction decreases as the "*A*" sintering point increases, and approaches zero as the "*A*" sintering point approaches and exceeds 2500°F.

Respectfully submitted,
SINTERING TEST SUBCOMMITTEE,
FOUNDRY SAND RESEARCH COMMITTEE
J. B. Caine, *Chairman*.

H. W. Dietert	C. M. Saeger, Jr.
L. B. Osborn	H. F. Taylor
W. L. Roueche	R. O. Wertz

NOTE: Since the presentation of this report, we have been fortunate in having J. A. Rassenfoss of the American Steel Foundries check the sintering points of the same sands shown in Table 1. His results are as follows:

Steel Facing Sand		*Iron Sand*		*Non-Ferrous Sand*	
"A" Point	*"B" Point*	*"A" Point*	*"B" Point*	*"A" Point*	*"B" Point*
°F.	°F.	°F.	°F.	°F.	°F.
2313	2925	2255	2480	....	2250

The results check within the same limit of error as shown in Table 1. Mr. Rassenfoss and Mr. Jacobson of Griffin Wheel Co. have had no previous experience with the committee. The only information they had were the published reports of the committee. This encourages us to expect reliable data on sintering in the future if every one will follow the procedure as given in the reports of the Sintering Test Subcommittee.

Appendix I

MOUNTING OF SANDS FOR MICROSCOPIC EXAMINATION

As interest has been shown in the photomicrographs in this report, it was thought advisable to include details regarding the mounting methods used. It required several months work to find a suitable mounting medium and it is hoped that these details will save those interested time in working out the details.

If the only information required is the size and shape of the sand grains, the simplest method is to scatter the sand on a glass plate, examine or photograph them with oblique illumination. However, knowledge of the exact spacing and distribution of the sand grains after ramming and after contact with the metal is becoming increasingly important. To do this satisfactorily, it is necessary to mount the sand specimen and not only hold the specimen together, but also to fill the voids so that only one plane can be seen. As the depth of focus of any objective is limited, any sand grains that are not on one plane confuse the picture. For example, if the surface is being examined for fusion, two overlapping grains will look exactly as if they have fused together. What has happened is that the outlines of the grain that is out of focus are blurred and look like they are fused, whereas in reality they have not.

The mounting material then must penetrate all the voids in the specimen as well as surround it and hold it together. It also must be opaque so that only one plane can be seen. The low melting alloys, containing lead, tin and zinc, simply will not wet the sand specimen no matter how liquid they are. They can be made to surround the specimen, but will not penetrate. Copper will penetrate into the sand but has its disadvantages in that it must be heated to over 2000°F. to be sufficiently liquid and also because its reflectivity is so much greater than sand that, although these specimens are satisfactory for visual examination, it is almost impossible to photograph them.

At the suggestion of Dr. Ries and Dr. Shaub, a bakelite varnish, "Bakelite Resenoid," was tried with good results. Its penetrating qualities are very good and it can be hardened at 375°F. The procedure is as follows:

Saturate the specimen by immersing it in the "Bakelite Resenoid" for a few minutes and place it in an oven at 100-110°F. with the surface to be examined up. Allow it to come up to temperature and hold at this temperature for an hour or so. If the Bakelite soaks into the sand, add more Bakelite from time to time by dropping it on the sand specimen, until there is an excess covering the surface. Increase the temperature slowly to 375°F. If the temperature is increased too fast the volatile constituents will boil and the Bakelite will be full of holes.

Bake at 375°F. for 36 to 48 hours. Cool and polish like any metallographic specimen. Use oblique illumination for sand and vertical illumination for sand-metal mixtures. The Bakelite will harden after a few hours at 375°F. but will be transparent. It requires 36 to 48 hours to get the hard opaque form that is desired.

The "Bakelite Resenoid" can be obtained from the manufacturer. the Bakelite Corp., New York. It is usually more convenient to get small quantities from the grinding wheel manufacturer in your locality. This is the same material used to bond high speed grinding wheels.

DISCUSSION

Presiding: DR. H. RIES, Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

Co-Chairman: H. A. DEANE, Brake Shoe & Castings Division, American Brake Shoe & Foundry Co., New York, N. Y.

CHAIRMAN RIES: The Subcommittee on Sintering Test deserves great

credit for the tremendous amount of work it has done. The report shows the amount of work carried on, and how important it is to get this work standardized. There has been a great deal of trouble with the sintering test, and different operators have sometimes obtained widely differing results.

H. J. WENDT[1]: Figure 4 showed a sand that started to sinter; the voids got larger. What relation is there between sintering and hot permeability?

MR. CAINE: I do not know. I would even hesitate to guess. The permeability of the non-ferrous sand after fusion, of course, cannot be measured. It must be very high. There is no opening up of voids throughout the whole sand specimen, and various sands act differently. Some will melt completely at the surface. The sand 1/16-in. back will have the original dry permeability. Some will open up for as much as ½-in. back of the sand-metal surface. Are you speaking of the hot permeability of the fused sand or the 2-in. specimen as a whole?

MR. WENDT: Both the 2-in. specimen as a whole and what relation it would have to the mold.

MR. CAINE: The hot permeability will increase. How much, I cannot say. I do not think it would be possible to determine it accurately, because the specimen is no longer uniform.

MR. WENDT: In practice, we have found that sand which sinters will cause a number of scales on a large casting, shiny gas pockets, and it seems that permeability is retarded before the hot metal.

MR. CAINE: It is pretty hard to say anything definite. There are a number of sands that fuse and produce a glaze on the surface. In such instances, when the glaze is produced, the permeability drops to zero. With 50°F. higher temperature, the glaze starts to open up. Then, of course, you increase your permeability tremendously. If you can keep that glaze from not opening up, you are doing well. You have a wonderful opportunity to prevent penetration. It has been my experience, personally, that it is extremely hard to control that glaze.

RUSSELL MANLEY[2]: What percentage of clay did you have on that steel sand?

MR. CAINE: Two per cent bentonite was added with 3 per cent colloids present in the base sand, making a total of 5 per cent total A.F.A. clay.

MR. MANLEY: What were the percentages on the gray iron and non-ferrous sands?

MR. CAINE: Twenty-seven and 28 per cent, respectively.

MR. MANLEY: We have just started some work on naturally bonded sands to determine what relationship, if any, exists between the sintering point of the new sand and the individual fusion points of the sand grains and the clay. We wash the clay from the sand, and then run a cone fusion point on the clay by itself and the washed grain by itself.

We tried a sand with 18 per cent clay, and 85 per cent of the grains pure silica. The sintering point on this was approximately 2250°F., but the clay bond was completely fused at 2100°F. Observation of the reac-

[1] Rundle Manufacturing Co., Milwaukee, Wis.
[2] Manley Sand Co., Rockton, Ill.

tion as the cone comes up to temperature shows that it starts to swell and begins to appear foamy as if there were a fluxing reaction occurring; then the point falls over to indicate fusion has occurred. Then as the increase in temperature is continued, the cone becomes more and more liquid and starts to stretch out. It finally will become liquid enough to pull apart, and the top of it will be carried out by the flame. The temperature at which this occurs corresponds roughly to the sintering point, and seems to indicate that the sintering point is the point at which the hot strength of the clay itself reaches zero.

Now, when the report of the tests on this sand just mentioned was discussed, this question naturally was raised, "If bentonite with a fusion point of 2300° to 2400°F. is used as a bond by practically every steel foundry in the United States, with the high pouring temperature of steel, why is not this bond just as good in comparison for gray iron, when the difference in pouring temperature is more than equal to the difference in the fusion points of the bonds?"

My reply was, "Yes, but steel foundries use practically all new sand every time, and they only use the sand once. This gray iron sand has 18 per cent to 20 per cent clay and is used over and over again. The amount of clay substance present changes the picture entirely, as there is no one that I know of who is using a brand new sand of 18 per cent to 20 per cent clay right up against the casting."

Microscopic examination shows that even above the sintering point, the reaction consists entirely of a fusion of the clay. We need a standard clay percentage to run these bonded sands, for we certainly cannot compare the sintering point of a brand new gray iron or non-ferrous sand that is used as an addition to a heap with a steel sand that is to be used just as is. The clay is the fluxing agent, and the percentage of unburned clay that is present ready to fuse has a tremendous effect upon the sintering point.

MR. CAINE: Please understand we are not testing the iron sand; we are trying to get an exaggerated picture to show something.

Another thing, the sintering points of the clay substance by itself are one thing and the sintering points of the sand-clay mixture are another. One reason that the steel foundries use bentonite, as against fire clay, is, in my opinion, because it gives a better peel, although the bentonite-sand mixtures have lower sintering points than the sand fire clay mixtures. Remember, we can have too high sintering points in sand just as well as we can have too low sintering points, and it is my firm belief that, in a number of steel foundries, the reason they are getting burnt-on sand is because of too high sintering points. It is not a matter of high and low sintering points; it is a matter of controlled sintering points. We only started on this work two years ago. The problem is becoming more complicated every day right now. Before long, it will clarify itself as we get more information.

L. B. OSBORN[3]: Getting back to Mr. Wendt's comment about hot permeability, we have observed that the higher sintering point sands do

[3] Hougland & Hardy, Inc., Evansville, Ind.

seem to have less tendency to scab and blow. Perhaps that is what you are getting at, Mr. Wendt. For example, we have found lots of instances where good foundries, working on good practice, were using high sintering sands of lower permeability than they formerly used when they were using a lower sintering type of sand with a higher permeability and they were now getting by with less blowing, perhaps, than they formerly had. It is probably due to the fact that the higher the sintering point, generally, the lower the temper water at which the sand can be rammed and still have sufficient hot strength.

MR. CAINE: That is true. The higher the sintering points in the sand-clay system, usually the lower the clay. The lower the clay, the less surface area we have and the less temper water required. That only applies to the sand-clay system. Put anything else in the mixture and you have to watch out. I have tried it and obtained some very surprising results.

MR. OSBORN: I am speaking primarily of the iron and non-ferrous metals. Those have been observations pointed out by various customers using the higher sintering type sands.

MR. CAINE: It appears that clay in the sand does not determine fully the sintering point of that sand. It depends upon what type of clay is present. In a sand with a given per cent clay, the sintering point may vary as much as 400°F., depending upon the type of clay substance that is present.

CHAIRMAN RIES: Mr. Caine, if you made up two mixtures of the same amount of sand and the same amount of clay with the sand differing in fineness, would you get the same sintering point?

MR. CAINE: No. The fineness of the silica will determine the sintering points as much as the clay. In fact, one of the best ways to lower the "B" sintering point of the sand is by the addition of minus 200 mesh pure silica. It lowers the melting point. Many people say that silica flour increases the sintering point. It increases the "A" point, where the ribbon first adheres to the specimen, and decreases the "B" point, the point of incipient fusion. With 100 per cent silica flour, the sand starts to fuse before it sticks to the ribbon. We cannot speak of sintering points; we are going to have to speak of "A" and "B" points, because the two points mean entirely different things and act entirely different.

Steel Pouring Refractories in Foundry Practice

By R. H. Stone*, Swissvale, Pa.

Abstract

This paper deals with the design, assembly and use of refractories in steel foundries. The author divides refractories into two classes, basic and acid. He discusses requirements for sleeves and tests made on sleeve bricks. He then takes up nozzles and how they are designed, the functioning of the stopper head-nozzle combination and factors in the wear of nozzles and stoppers. The flow of heat in the stopper and the selection and care of stopper heads is also discussed. Illustrations of stoppers and nozzles of various shapes and sizes, together with effects in usage, are included.

1. Judging from observations in many steel foundries, there is a wide variation in design of refractories and in the practice of assembly and use. As the object is similar in all these shops, namely, to maintain control over the flow of steel throughout the pour, and as the conditions are not too dissimilar, a study of composition and design of the refractories may be helpful in improving pouring practice.

Basic and Acid Refractories

2. Like the processes for making steel, refractories may be divided into basic and acid. All the plastic fire clays are silicious or acid and are attacked by the basic slags and iron oxide. Magnesia or magnesite is the only practical basic refractory available for steel pouring purposes. Chromite and zirconia are neutral refractories, but, due to certain physical properties, they are not encountered in steel pouring practice.

3. Clay-bonded refractories predominate in foundry steel pour-

*Vesuvius Crucible Co.

Note: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

ing because the process is frequently acid, or, in electric furnaces, the slag blankets are light and give little difficulty. In the foundries operating rather large basic furnaces, the problem of slag attack is met by simply increasing the diameter of sleeves to compensate for wash. In such plants, the stopper heads are larger and the clay-graphite composition of which they are made is practically immune to slag attack.

Requirements for Sleeve Assemblies

4. Considering the stopper assembly, the sleeves have the least burden as there is no mechanical load nor wash of steel. There is some slag attack in the case of basic steel, but as the slag level moves steadily lower during the pour this burden is well distributed. A reasonable density and medium firing in the manufacture of sleeves will give the necessary resistance to slag. Firing should be slightly lower than the vitrification temperature.

5. Obviously, the sleeves must not spall or crack off the rod and they should be only slightly reduced in diameter by slag erosion. If they meet these requirements, they will serve their purpose. Of course, succeeding shipments of sleeves must all be satisfactory; in other words, uniformity and dependability are necessary.

Tests on Different Sleeve Bricks

6. In a recent test[1] of several brands of sleeve bricks, the best showing, based on resistance to cracking or spalling and resistance to slag attack, was made by sleeves with P.C.E.* 32-33 (3137°F.); porosity 21.8 per cent; linear thermal expansion 77°F. to 1832°F., 0.570 per cent; and volume change between 212°F. to 392°F., small. Compared with these figures, the showing was not so favorable for sleeves with P.C.E. 23-26 (2894°F.); porosity 17 per cent; linear thermal expansion 77°F. to 1832°F., 0.615 per cent; and volume change between 1022°F. and 1112°F., large. In these tests, the majority of the sleeves were used in heats from an electric, basic-type furnace with tapping temperature around 2960°F.

7. The joints between sleeves are filled with a sand loam and fire clay mud, using enough material so that it is forced into the space between the rod and sleeve. This excess centers the sleeve and rod together. Many shops use an air setting refractory cement between the end sleeve and the graphite stopper head.

[1]Heindl and Cooke, "*Fire Clay Ladle Sleeves*," Journal, Bureau of Standards (March, 1938).

*Pyrometric cone equivalent.

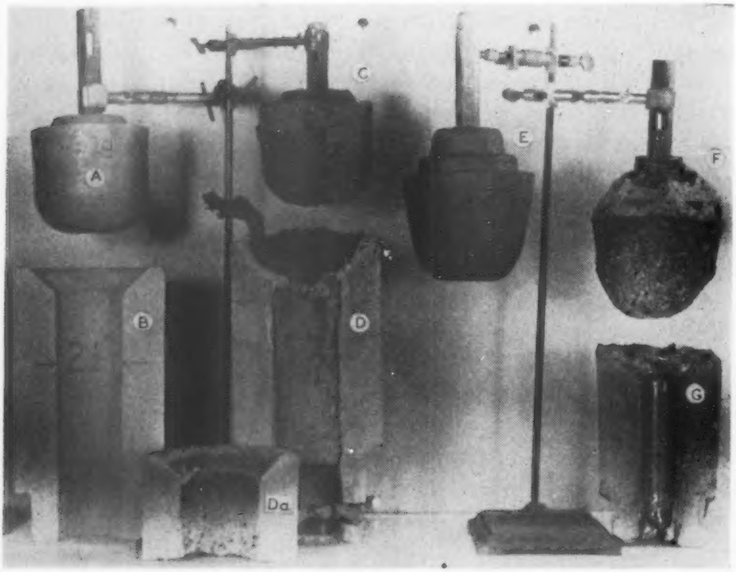


FIG. 1—*A*, *B*, *C* AND *D* SHOW ORDINARY-GRADE, LOW-FUSION, FIRE-CLAY NOZZLE BEFORE AND AFTER POURING BASIC HEAT OF 25 TONS. ILLUSTRATES CONFORMATION OF NOZZLE TO SHAPE OF GRAPHITE STOPPER-HEAD. NOZZLE *Da* IS AN AUXILIARY, 3-IN. DIAMETER NOZZLE USED FOR POURING HALF THE HEAT INTO ONE CASTING. IT IS THEN CLOSED FOR THE REMAINDER OF THE HEAT. DURING POURING, NOZZLE MATERIAL SQUEEZED FROM SEAT INTO FLOW-HOLE IS WASHED OUT. *E*, *F* AND *G* SHOW MEDIUM-GRADE NOZZLE. AFTER POURING 10-TON ELECTRIC STEEL HEAT, NOZZLE SHOWS ONLY SLIGHT CUPPING UNDER PRESSURE OF GRAPHITE STOPPER. MATERIAL SQUEEZED FROM SEAT NOT SUFFICIENTLY SOFT TO BE WASHED AWAY—MAY PARTLY BLOCK FLOW-HOLE. NO APPRECIABLE ENLARGEMENT OF FLOW-HOLE.

NOZZLES

8. Magnesite nozzles are used extensively in European shops but are almost unknown here in spite of having been mentioned often in reports. Several reasons may account for failure to adopt them. They are very refractory and consquently there is no enlargement of the hole as the pouring progresses which is considered desirable to compensate for the falling pressure of the steel as the ladle empties. Because they do not soften, the shut-off with the equally hard stopper head is frequently imperfect. On account of their high heat conductivity there is a tendency for the stream to freeze up unless the heat is very hot.

9. An effort has been made to retain the advantages of the clay nozzle by using various highly refractory inserts or combinations of clay and more highly refractory upper and lower halves of the

nozzle. Quoting an English authority, "Inserts of magnesia, mullite and high alumina materials have been used (in England) but have not solved the problem of nozzle erosion.[2]"

Functioning of Stopper Head-Nozzle Combination

10. Like any valve, the functioning of the stopper head-nozzle combination depends on one harder surface impinging on a softer one. Because the burden placed on the stopper head is the heavier, including as it does mechanical abrasion, higher temperature and chemical washing, it is customarily chosen as the hard refractory element in the valve (Fig. 1-B).

11. The nozzle usually provides the softer cushion and, therefore, its composition is such that it will soften slightly at steel pouring temperatures. Nozzles should have a coarse texture, that is, the surface of a fracture should show coarse particles but the density should be high and porosity low. It has been pointed out, however, that the total porosity as indicated by the percentage is of less importance than the distribution of this porosity, *i.e.*, numerous smaller pores in the steel pouring refractories are better than fewer larger ones[3]. Nozzles should be fired to incipient vitrification.

12. Nozzles made of clay graphite composition, like the stopper head, are occasionally used. They are open to the same objections as the magnesite nozzle. A combination nozzle, with the upper part made of fire clay and the bottom of clay graphite, is used in a few shops. Sometimes this type is made in two pieces, sometimes in one piece.

FACTORS IN THE WEAR OF NOZZLES AND STOPPERS

13. It has often been pointed out that the enlargement of the hole in the nozzle due to wash compensates for the falling pressure of the steel in the ladle and the result is a fairly steady rate of flow throughout the pour. The material washed away in the stream has been regarded as a necessary evil to obtain a desirable result. As a matter of fact there is less likelihood of inclusion in the steel if a constant rate of pouring is maintained than if no wash is permitted and the flow towards the end of the pour becomes very slow.

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[2]Rees, Walter, Dr., "*Steel Mill Pouring Pit Refractories*," INDUSTRIAL HEATING (December, 1938).
[3]Chesters, J. H., "*Casting Pit Refractories*," THE IRON AGE (November 20, 1941), p. 48.

The danger of entrapping foreign material as inclusions is greatly increased under the latter conditions.[3]

14. It should be emphasized, however, that the wear or wash should be uniform. If the wash is uneven it is an indication of several possible faults: the stopper may be set too far off center, producing a side thrust; the refractories may be "off" in burn or composition; the nozzle may be set crooked; the nozzle may have become cracked in warming up. Actual cases have been observed just before the heat is taken in the ladle of nozzles that had vertical cracks running down over the seating face due to too rapid heating. Following these cases through the pour, invariably there was a leaking, if not a running nozzle, and examination after the pour revealed that the initial hair-line crack had enlarged to resemble a deep ravine. In such cases the whole seating area becomes oval

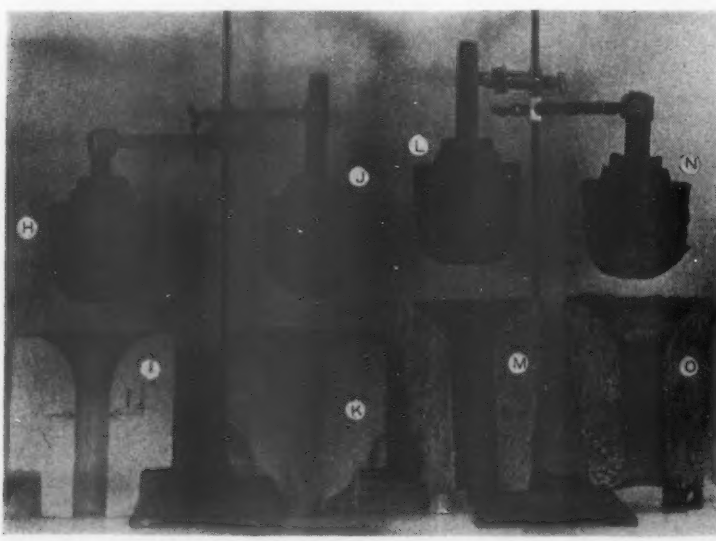

FIG. 2—*H, I, J* AND *K* SHOW NOZZLE MADE OF HIGH ALUMINA CLAY—FUSION POINT, 3100°F. SHOWS NO DEFORMATION UNDER STOPPER. NO ENLARGEMENT OF FLOW-HOLE. POURING RATE SLOW AT END OF HEAT. ELECTRIC FURNACE, CHROME-MOLYBDENUM STEEL, 5-TONS, 2980°F. POURING TEMPERATURE. POURING TIME, 20 MIN., 30 OPENINGS. GRAPHITE STOPPER-HEAD SHOWS SOME DEFORMATION, INDICATING IT IS SLIGHTLY SOFTER THAN NOZZLE. WITH THIS RELATIONSHIP, GOOD SHUT-OFFS WOULD BE OBTAINED. *L, M, N* AND *O* SHOW FIRE-CLAY NOZZLE SAID TO BE CARBON IMPREGNATED. SLIGHT DEFORMATION OF SEAT; SOME RESTRICTION OF FLOW-HOLE. ELECTRIC FURNACE STEEL, 4-TON HEAT. SECTION OF STOPPER (*N*) SHOWS EXCELLENT CONDITION OF PLUG AFTER POUR.

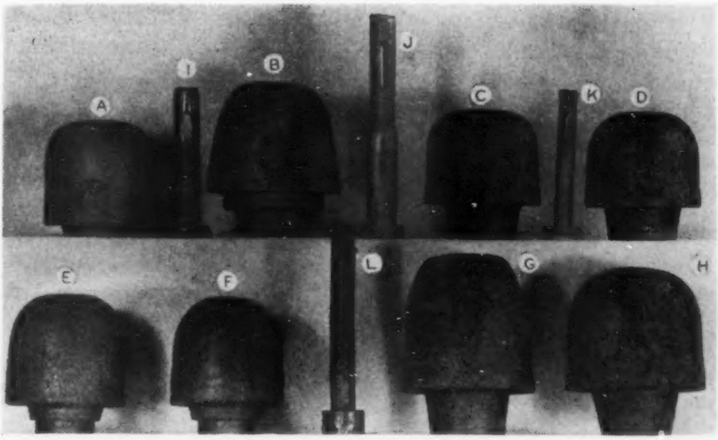

FIG. 3—PAIRS OF STOPPERS—*A* AND *B*, *C* AND *D*, ETC., SHOW EXAMPLE OF CHANGES IN DESIGN TO IMPROVE POURING PRACTICE. LEFT, STOPPER IN PAIR, OLD DESIGN; RIGHT, IMPROVED DESIGN. TENDENCY IS TOWARD MORE POINTED STOPPER OR HEAVIER. THE STOPPER-PINS ARE GOOD EXAMPLES OF SQUARE SHOULDER BETWEEN HEAD AND SHANKS WHICH GIVES GOOD BEARING ON STOPPER HEAD. PIN *J* IS MACHINED FOR GOOD FIT IN STOPPER-ROD. PIN *L* HAS EXTRA LONG HEAD, DESIRABLE IF HEATS ARE HOT AND POURING IS PROLONGED.

and the stopper, yielding to this distortion, likewise is squeezed into an elliptical section (Fig. 4).

15. Correct setting of the nozzle is, of course, influenced by the design and condition of the ladle lining. A poor bottom lining increases the difficulty of setting the nozzle properly.

DESIGN

16. The majority of nozzles used are designed with a streamlined orifice, curving from the top with an ample radius at the seating surface and running smoothly into the final diameter of the hole itself (Fig. 2-1). It may be found necessary, as the size of heats increases, to increase the length of the nozzle in order to produce a full, non-spraying stream. Thus, if a nozzle 7-in. in height is satisfactory for a two-ton heat, good practice may require a 10-in. nozzle for a 30- or 40-ton heat.

STICKING

17. Occasionally, complaint is heard of the stopper head and

nozzle sticking together when shut between flasks. One shop overcomes this by boiling the clay nozzle in tar until saturated.[4] This is said also to reduce cracking of nozzles.

OBTAINING GOOD CONTACT

18. Both nozzle and stopper head manufacturers strive to produce articles that will make a perfect circular contact, and the heads and nozzles, in fact, are put in service as received in most cases and hold the steel without leaking. A few users, however, make a practice of grinding the contact surfaces of the nozzles and, sometimes, the stoppers. To facilitate this grinding, one shop has designed a nozzle with the face at the top sloping at 30°; then, at point of contact with the stopper, the slope changes abruptly to 60° so that the stopper rests on the ridge of the angle formed by the two sloping faces. If, when the stopper is set on the nozzle, it is found that the contact is imperfect, a very little grinding will true up the nozzle.

DRYING STOPPERS FOR LARGE AND SMALL HEATS

19. Many steel foundries pour small heats when compared to the ingot shops. The stopper rods are correspondingly small, and the drying equipment is very simple. Frequently, the drying is done simply in the open by exposure to warm ladles or to a salamander. Satisfactory results are obtained by these means where the stoppers are only 3 or 4 ft. long.

20. For larger heats (5 tons and higher) special provision should be made for drying stopper rods. The best installations provide for hanging the rods vertically head down with the source of heat at the bottom. If a gas flame is used for drying, the heat should be applied indirectly because when the stoppers are cold, moisture will condense on them from the gas flame.

21. Ingenious use is made with good economy in one plant by using the slag from the ladle as the source of heat. The slag is poured into a box under the stopper oven.[5]

22. The essential principles in drying stopper rods are—

(1) The handling and support of the rod in the drier must be such that the joints are not loosened nor the stopper head damaged.

(2) The entire assembly must be moisture-free before using in the ladle.

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[4] Bacon, N. H., *"The Metallurgical Observer Strives for Improved Quality,"* STEEL (December 1, 1941).

[5] Klein, H. T., *"An Inexpensive Stopper Drying Oven,"* STEEL (December 1, 1941).

Precautions in Handling

23. Injury to the stopper, particularly the head, must also be guarded against while removing the stopper from the drier and setting in the ladle. Also, the rigging on the ladle should be kept in first class repair so that the stopper will be firmly operated. Periodical inspection and over-haul of the rigging should be the rule.

Flow of Heat

24. An important but seldom considered element in the successful performance of the stopper head and nozzle is the heat flow in

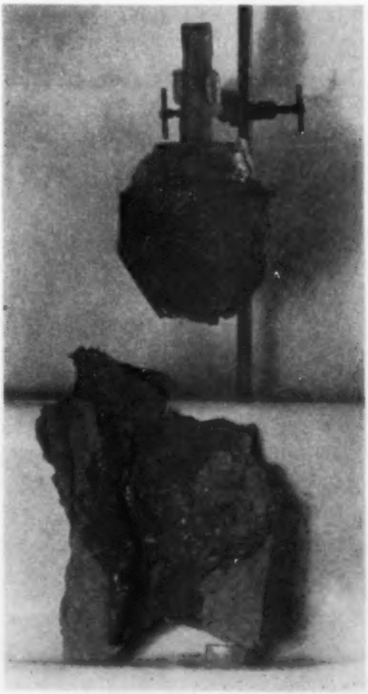


Fig. 4—Pouring with This Stopper and Nozzle Ended in a Heavy Leaker. The Nozzle Was Cracked When Set or Cracked Later Due to Too Rapid Drying Out or Preheating. This Crack Enlarged so Rapidly During Pouring, a Shut-off Could Not Be Maintained. At the End of the Pour, the Crack Was Enlarged to a Deep Gully. Note Deformation Imparted to Graphite Stopper Head and Channel Cut Opposite the Crack in the Nozzle by the Leaking Steel.

the stopper.[6] The gradient of the temperatures at the contact of nozzle and stopper and of the steel stopper rod is such that there is an appreciable flow of heat from the seat. This flow materially aids in maintaining the nozzle and stopper at suitable operating temperatures. If there were no such flow, overheating and excessive fusion of both nozzle and stopper would result. When clay stoppers were formerly used in steel pouring, particularly in ingot shops, it was not uncommon to find 2/3 of the head washed away during the pour due to such overheating.

25. Unconsciously, perhaps, and more or less indirectly, this thermal relationship largely governs the determination of the conductivity of the graphite stopper head; also, the size and proportion of the stopper, the diameter and analysis of the steel stopper bolt; the diameter of the steel stopper rod and the diameter of the sleeve brick. It is the sleeve brick, of course, that we rely on to keep the steel rod relatively cool and maintain the gradient.

SELECTION AND CARE OF STOPPER HEADS

26. In selecting the proper stopper head it has usually been found that the relatively pointed head gives better practice than the blunt type (Fig. 3).

27. The undercut should be sufficiently deep to protect the stopper bolt head, and for this purpose should not be less than 1½-in. deep regardless of size of stopper. The mix for filling the undercut may be made of 2/3 ground stoppers and 1/3 good fire clay, or it may be purchased ready mixed. It goes without saying that it should be as refractory as the stopper head, but it is surprising how frequently trouble in steel pouring originates with plugs melting out. This usually is the result of substituting the first thing that comes to hand when the regular supply gives out.

STEEL PINS

28. The conductivity of the stopper should be such that the steel pin is not melted during the pour. The pin, however, should be of 0.10 per cent carbon, or under, because of the higher melting point of that grade.

JOINT BETWEEN END SLEEVE AND STOPPER HEAD

29. It is customary to have a deep joint between the end sleeve

[6]Beasley, H. V., "*Nozzle and Stopper Rod Assemblies*," BLAST FURNACE AND STEEL PLANT (October and November, 1933).

and the stopper head, usually 1½-in. to 1¾-in. deep. This gives protection against entry of steel at this joint. One variation is to have a double offset, in some cases requiring a double recess in the sleeve, and, in other cases, the second offset or neck is about the same diameter as the stopper rod and fits up into the sleeve accordingly (Fig. 3-B).

30. Many shops, however, use a stopper with a short neck (Fig. 3-F) so that no special end sleeve is required. With careful assembly, such a combination will give good results, although there is only a narrow safety margin.

ACKNOWLEDGMENT

31. Grateful acknowledgment is made to the following firms and individuals who furnished the material for the illustrations: J. C. Lind, American Steel Foundries, East Chicago, Ind.; Ford Chaney, Crucible Steel Castings Co., Cleveland, O.; W. F. McKee, Key Co., East St. Louis, Ill.; and Martin Baker, Pittsburgh Steel Foundry Co., Glassport, Pa. The photographic work was done by Linwood Thiessen, Vesuvius Crucible Co.

DISCUSSION

Presiding: H. H. BLOSJO, Minneapolis Electric Steel Castings Co., Minneapolis, Minn.

J. R. ADAMS[1]: In some plants it is the practice in constructing and building a stopper to leave the space between the hole in the sleeve and the rod vacant. In other plants, it is the practice to fill this void with sand. What is the recommended practice?

MR. STONE: Both practices are followed. In filling the hole with sand the heating of the steel rod is reduced somewhat, due to the fact that the conduction of heat by air currents in that space is prevented. An equally good practice is to let the excess mortar at the joint flow into that space and make a contact between the sleeve and the stopper rod at intervals. That serves the same purpose of breaking up the space surrounding the steel rod. I do not think there is any objection at all to using sand.

MR. ADAMS: What is the proper technique with respect to the expansion under heating of the stopper?

MR. STONE: About ⅛-in. per ft. is allowed. There are all sorts of devices to allow for that expansion. Usually the nut at the top of the stopper rod which holds the ring down on the top sleeve is simply backed off the required amount in proportion to the length of the stopper rod.

[1] Crucible Steel Castings Co., Lansdowne, Pa.

Another method is to have a spring under the nut. That works satisfactorily for a while, but the spring usually loses its value under the heating that it receives. Another method is to insert a wooden collar under the nut, which burns out. However, I do not believe the wood burns out quickly enough. Generally, good results are obtained by simply backing the nut off, and leaving the space open, provided it is done after the stopper is set.

E. H. NOACK[2]: Dating back 25 years, when we first started our steel foundry, we had a great deal of trouble with the stoppers in our bottom pour ladle. Our main trouble was the clay sleeves cracking and letting the steel get to the rivet in the stopper. After considerable trouble and throwing away a few carloads of skulls, which were mostly the full heat of the furnace, we discovered we were keeping the nut which held the sleeves against the graphite stopper too tight, and the expansion of the sleeves caused them to crack. We solved our problem by drawing the nut just tight enough to seat the clay seal between the joints, then relieved the nut about 1/16.

MEMBER: We have had very good results with a ⅜-in. coil spring, coiled in 2- or 2½-in. coils, and tightened by hand which allows the sleeves to expand without getting out of place. We also fill the voids between the sleeves and the stopper with sand, principally to keep the clay in the joints from getting out of place in handling. Sand is a very good insulator, and it helps to insulate the stopper rod from the heat of the metal. I believe the principal reason for filling those clay sleeves with sand is to facilitate ease of handling without breaking the joints between the sleeves.

MR. STONE: What was the life of the spring? Did you find any deterioration?

MEMBER: The springs do deteriorate. The stopper rods must be of sufficient length to have enough room above the largest heats poured so that the springs will never become immersed in slag. Under such conditions the springs will last at least 3 to 4 months; once they are immersed in slag they are finished.

MEMBER: Does grinding the stopper into the nozzle tend to destroy the surface to such an extent that it might reduce the life? Does it destroy the glaze or surface finish that tends to permit additional cutting?

MR. STONE: Other things being equal and with a good set-up, I think that would do no harm. Of course, if a little of the interior of either the nozzle or stopper head is exposed, it might be a little softer under the surface and, consequently, liable to wash more rapidly. I really do not think that limited grinding does any harm if both the nozzle and the stopper are properly burned.

[2] Monarch Foundry & Engineering Corp., Stockton, Calif.

Effects of Ladle Inoculation on An Austenitic Cast Iron

By J. T. Eash*, Bayonne, N. J.

Abstract

In an investigation of the effects of ladle inoculation on austenitic cast iron containing 14 per cent nickel, 6 per cent copper and 2 per cent chromium, it was found that the transverse and tensile properties of 2.25 per cent carbon heats were markedly improved by ladle additions of ferro-silicon, whereas with high carbon contents, only moderate improvements were obtained. The Izod impact of all grades was improved by silicon inoculation. Austenitic nickel-copper-chromium cast irons made from steel charges had superior properties and were improved to a greater extent by inoculation than were castings made from cast iron scrap. Dendritic graphite and carbide structures were found associated with low properties, while inoculated heats had random carbides and flake graphite. These irons possessed outstandingly high toughness and deflection properties.

1. In the past two decades, the gray iron industry has advanced ordinary cast iron from the position of a non-uniform low strength material to a high quality product where strengths in excess of 60,000 lb. per sq. in. are nothing unusual. During this time austenitic nickel cast irons of the "Ni Resist" type containing about 14 per cent nickel, 6 per cent copper and 2 per cent chromium were developed for use in applications requiring greater corrosion and heat resistance than ordinary gray iron. Such austenitic irons inherently have greater ductility and lower strength than the basically different pearlitic irons of the same carbon and silicon content; however, steady progress has been made towards improving their mechanical properties so that tensile strengths as high as 40,000 lb. per sq. in. are now readily obtainable.

2. This advancement is a result of increased knowledge of the benefits derived from the control of melting technique, charge materials, composition and ladle treatment. The present investiga-

* Research Metallurgist, Research Laboratory, International Nickel Co., Inc.
Note: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

Table 1

COMPOSITIONS AND PROPERTIES OF AUSTENITIC NICKEL-COPPER-CHROMIUM CAST IRONS—75 PER CENT STEEL CHARGES

No.	Composition (Per Cent) TC	CC	Si	Mn	Ni	Cu	Cr	Ladle Si Per Cent	T.C. + 1/3 Si Per Cent	BHN	Transverse[1] Load Lb.	Transverse[1] Def. In.	Tensile Strength lb. per sq. in.	Izod AB Ft. Lb.
All heats contain nominal alloy content				(1)†	(14)†	(6)†	(2)†							
1	2.34	0.79	1.03					0.0	2.68	213	3395	0.120	40,400*	53
2	2.23		1.52					0.40	2.74	180	3990	0.258	41,200*	111*
3	2.38		1.14					0.50	2.74	183	4475	0.317	41,800*	1-54
4	2.29	0.69	1.72					0.70	2.86	170	4770	0.481		2-64
5	2.15		2.15	1.20	13.87	6.10	2.06	1.00	2.87	173	4820	0.680	42,300*	1-94
6	2.25	0.70	1.70					1.20	2.82	177	5230	0.600	46,600*	2-50
7	2.48		1.10					0.0	2.85	196	3415	0.124	36,000	46
8*	2.45		1.97	1.18	14.15	6.34	2.04	0.0	3.11	180	3300	0.142	35,900	31
9	2.48		0.96					0.50	2.80	191	4350	0.460	41,780	99, 1-89
10	2.46		1.80					0.70	3.06	170	4670	0.534	36,800*	1-118
11	2.37		2.62					0.75	3.24	166	4650	0.580	34,600	82, 1-80
12	2.47		1.78					1.20	3.06	171	4820	0.600	36,080	1-100
13*	2.77	0.98	0.68					0.0	3.00	200	3580	0.134	39,800	45
14*	2.90	0.88	1.06					0.0	3.25	180			38,000	68
15*	2.89		1.27					0.0	3.31	174	3535	0.200	36,900	42
16*	2.89		1.93					0.0	3.53	164	3720	0.333	33,020	100
17	2.80	0.76	1.68					0.70	3.36	162	4060	0.560	37,180	1-90
18	2.80		2.00					0.70	3.47	165	4065	0.484	36,860	1-35
19	2.70	0.85	1.84					1.20	3.31	168	4225	0.387	37,730	1-74

† Calculated. * Single test. [1] Transverse—12-in. span.
NOTE: Properties are average of two or more tests except where indicated.

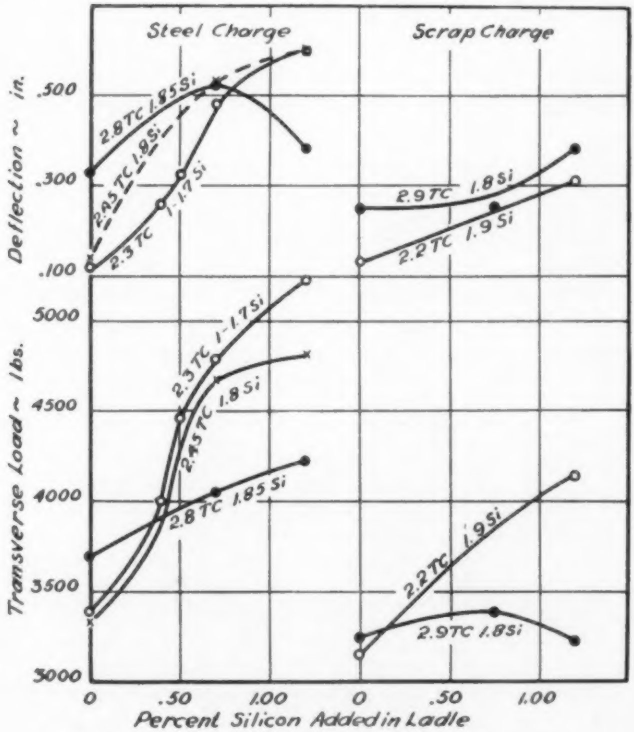


FIG. 1—EFFECT OF LADLE INOCULATION ON TRANSVERSE PROPERTIES.

tion deals with the effects of these production factors on the mechanical properties, with particular emphasis being placed on ladle inoculation.

3. A number of articles have been written on the properties and applications of austenitic cast iron as can be seen in the list of references at the end of the paper. The properties covered in these include tensile, transverse, impact, microstructure, wear, creep, heat resistance, corrosion resistance, etc. While tensile values of 20,000 to 35,000 lb. per sq. in. are quoted, no systematic effort had been made to correlate fundamental factors involved in production with physical properties to assist one in producing a consistent quality of product. The present work fills a need in this direction.

EXPERIMENTAL PROCEDURE

4. The austenitic iron used was a typical commercial composi-

tion and contained 14 per cent nickel, 6 per cent copper and 2 per cent chromium. Some of the heats were made with steel charges and others from cast iron scrap; the former were carburized with petroleum coke. Alloys were added to the charge in the form of a pig containing 58 per cent nickel, 24 per cent copper and 8 per cent chromium. The irons were melted in an induction furnace, heated to 2850°F. and poured at 2650°F. into arbitration bar cores. Ladle additions of ferro 85 silicon were made to most of the heats as indicated.

5. Transverse properties were determined on a 12-in. span to secure the greatest number of check results possible, and Izod AB and tensile tests were made on the broken ends. The tensile speci-

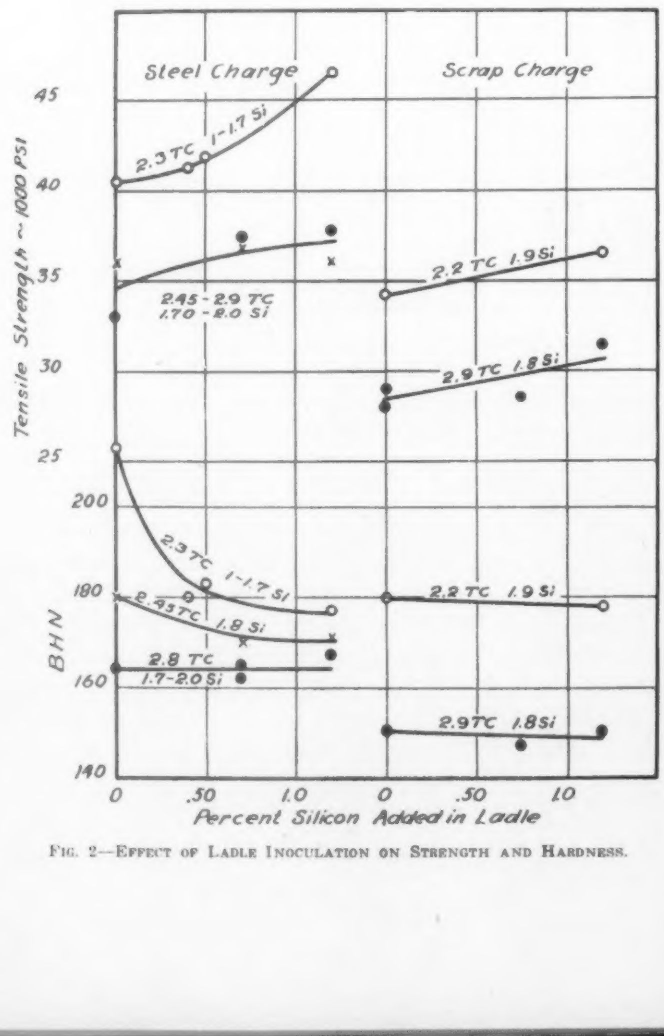


FIG. 2—EFFECT OF LADLE INOCULATION ON STRENGTH AND HARDNESS.

Table 2

COMPOSITIONS AND PROPERTIES OF AUSTENITIC NICKEL-COPPER-CHROMIUM CAST IRONS—SCRAP CAST IRON CHARGES

No.	Composition (Per Cent) TC	CC	Si	Mn	Ni	Cu	Cr	Ladle Si Per Cent	T.C. + 1/3 Si Per Cent	BHN	Transverse[1] Load Lb.	Transverse[1] Def. In.	Tensile Strength lb. per sq. in.	Izod AB Ft. Lb.
All heats contain nominal alloy content				(1.0)†	(14)†	(6)†	(2)†							
20	2.20		2.11					0.0	2.90	180	3165	0.134	34,250	34
21	2.21		1.04					0.50	2.56	183	4140	0.205	42,400*	1-20
22	2.22		2.85	1.04	14.17	6.48	2.02	0.75	3.17	162	4020	0.355	35,150	1-44
23	2.18		1.79					1.20	2.77	178	4155	0.315	36,500*	1-46
24	2.73		0.63					0.0	2.94	181	3655	0.144	37,040	47
25	2.78		1.18					0.50	3.17	161	3515	0.240	31,900*	97
26	2.55	0.65	1.92					1.20	3.19	171	4095	0.398	38,530	1-60
27	2.67	0.60	1.91					1.20	3.31	155	3370	0.349	31,400	1-42
28	2.99		0.58					0.0	3.19	170	3285	0.160	34,270	62
29	2.86		1.66	0.82	14.04	6.10	2.22	0.0	3.41	150	3500	0.240	28,000	92
30	2.65		2.50	1.18	13.97	5.95	2.10	0.0	3.48	147	3265	0.203	25,500	63
31	2.95		1.89					0.0	3.58	150	3040	0.265	28,970	85
32	2.88	0.58	1.67	0.84	14.06	6.02	2.17	0.75	3.44	147	3400	0.250	28,600	90
33	2.95		2.13	1.65	14.33	6.33	2.06	0.75	3.66	150	3500	0.290	26,600	95
34	2.85	0.67	1.81					1.20	3.45	150	3225	0.389	31,500	110

† Calculated.
[1] Transverse—12-in. span.
* Single test.

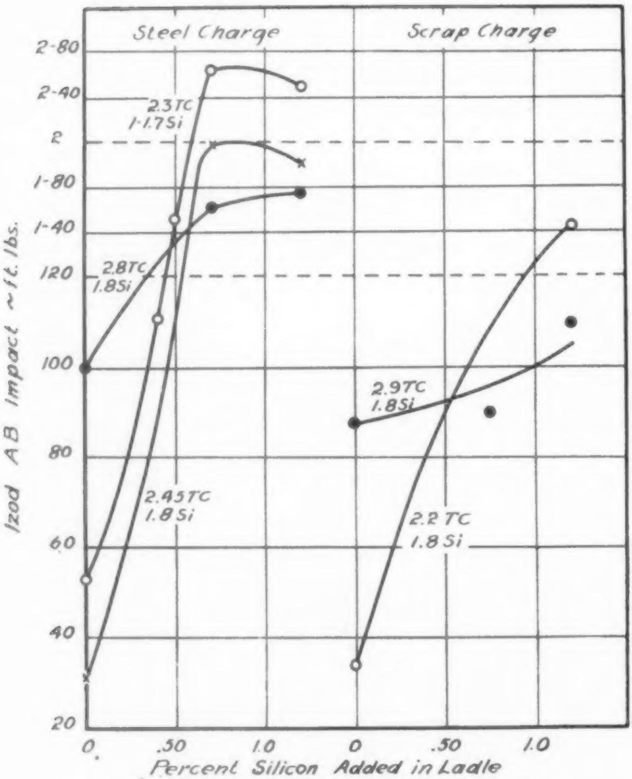


FIG. 3—EFFECT OF LADLE INOCULATION ON IZOD AB IMPACT.

men had a reduced section of 0.798-in. dia.* Carbon and silicon determinations were made on each of the heats and a few were analyzed for other elements as shown in Tables 1 and 2 to be sure the alloy content was in the desired range.

6. Details of the mechanical properties are listed in Tables 1 and 2 and the values are plotted in Figs. 1 to 3. The melts have been divided into groups according to their carbon content and the curves shown in the figures are identified according to the average final composition of each group.

DISCUSSION

Steel Charge Heats

7. It can be seen that the transverse properties of irons made

* The Izod specimens were unmachined and unnotched.

Table 3

COMPARISON OF AS CAST AND MACHINED NICKEL-COPPER-CHROMIUM CAST IRON TRANSVERSE BARS

Ladle Si per cent	Composition of Iron[1] TC per cent	Si per cent	Mn per cent	1.2-In. Cast Bar Transverse[2] Load lb.	Def. in.	Izod AB ft. lb.	Tensile Strength lb. per sq. in.	BHN	Graphite Pattern	1.2-In. Machined Bar Transverse Load lb.	Def. in.	Izod AB ft. lb.	Graphite Pattern
0.0	2.16	2.44	1.45	3210	0.169	39	34,470	146	Very fine dendritic	3725	0.175	48	Medium dendritic
1.0	2.12	2.45	1.37	4245	0.513	1–76	36,000	143	Fine flake	4315	0.427	118	Medium flake
0.0	2.70	2.20	0.88	3245	0.218	1–35	27,600	128		3015	0.189	1–71	Thick flake
0.75	2.74	2.07	0.88	3520	0.289	1–66	25,650	119		2940	0.200	1–77	Thick flake

[1] Includes also 14 per cent Ni, 6 per cent Cu and 2 per cent Cr.
[2] Transverse—12-inch span.

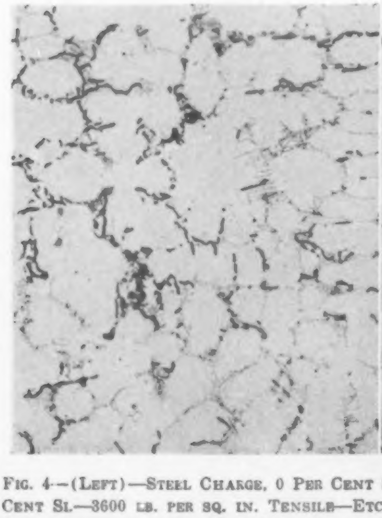
from steel charges containing 2.3 and 2.45 per cent carbon were raised substantially as the silicon ladle addition was increased to over 1 per cent while the high carbon austenitic iron was improved only moderately. The peak result in the latter was secured at 0.75 per cent silicon addition.

8. The tensile strengths of 2.3 per cent carbon irons were increased appreciably and the hardness decreased by the ladle treatment. The higher carbon nickel-copper-chromium irons were at lower strength and hardness levels and these properties were not affected to any great extent by ladle additions.

9. The Izod AB impact resistance at all carbon contents was improved most strikingly, with the optimum ladle addition being at about 0.75 per cent silicon. Some of the bars actually required two or three blows of the hammer delivering 120 ft. lb. energy to cause fracture. In the impact chart, Fig. 3, the prefix numbers 1 —or 2—indicate the number of blows the specimen was struck without failure and the latter part of the coordinate shows the energy absorbed on the second or third blow respectively.

Cast Iron Scrap Charge Heats

10. A comparison of the nickel-copper-chromium irons made



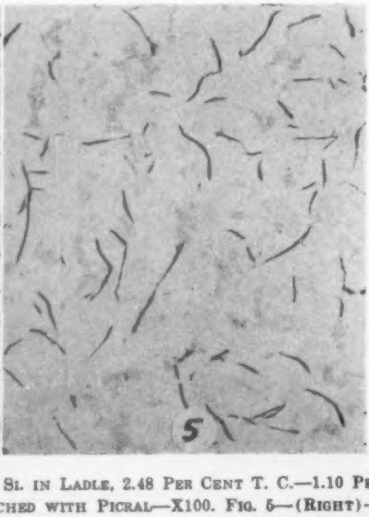


FIG. 4—(LEFT)—STEEL CHARGE, 0 PER CENT SI. IN LADLE, 2.48 PER CENT T. C.—1.10 PER CENT SI.—3600 LB. PER SQ. IN. TENSILE—ETCHED WITH PICRAL—X100. FIG. 5—(RIGHT)—STEEL CHARGE 1.20 PER CENT SI. IN LADLE, 2.25 PER CENT T. C.—1.70 PER CENT SI. 46,-000 LB. PER SQ. IN. TENSILE—ETCHED WITH PICRAL—X100. BOTH AUSTENITIC CAST IRONS CONTAIN 14 PER CENT NICKEL, 6 PER CENT COPPER AND 2 PER CENT CHROMIUM.

from steel and cast iron scrap charges shows the latter to possess a generally lower level of properties and to be less affected by the ladle additions.

11. It is quite obvious that to secure maximum results, a high proportion of steel should be used and the carbon content kept low. A casual survey of Tables 1 and 2 shows that the strength and response to inoculation were dependent to a considerable extent upon the graphitizing power of the iron as expressed by the sum of per cent T.C. + 1/3 Si. The graphitizing power of the other elements present need not be considered in this comparison since they were held constant. As the carbon and silicon increased, the strength decreased for both inoculated and uninoculated irons.

Microstructure vs. Properties

12. The properties of the specimens were found to have a consistent relation with their microstructures; low properties were associated with carbide and graphite in a dendritic arrangement, whereas high values were obtained in castings having a more or less random distribution of these constituents, when compared at equivalent compositions.

13. Numerous microexaminations showed the uninoculated low carbon or low T.C. + 1/3 Si. nickel-copper-chromium irons to have a dendritic structure which was replaced by flake graphite upon ladle treatment, with an attendant increase in strength, as shown in Figs. 4 and 5. The matrix structure in all cases consisted of austenite as shown in Fig. 6. It is obvious from this that the same relations between graphite structure and properties hold for the austenitic irons as for the pearlitic gray irons.

14. The high carbon austenitic iron had rather good arrangement of flake graphite without inoculation, so there was less change to be affected by ladle treatment and hence little change in tensile strength. Their greater total carbon content caused them to have lower strength than the low carbon irons.

15. The photomicrographs shown in Figs. 4 and 5 were taken of midsections and represent the average structure of the irons and the structure of the tensile bars. The transverse and impact properties, however, were dependent upon surface structures and in this location the dendritic structures were more pronounced and apt to form, due to rapid cooling, and cause low ductility. Even in the high carbon irons there was a tendency for the surface to be

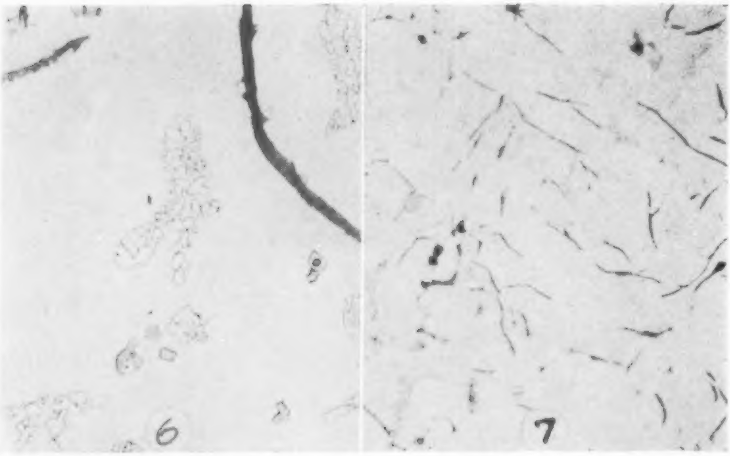


FIG. 6—(LEFT) STEEL CHARGE. 1.20 PER CENT SI. IN LADLE, 2.25 PER CENT T. C.—1.70 PER CENT SI. 46,000 LB. PER SQ. IN. TENSILE—ETCHED WITH PICRAL—X500. FIG. 7—(RIGHT) SCRAP IRON CHARGE, 1.20 PER CENT SI. IN LADLE—2.18 PER CENT T. C.—1.79 PER CENT SI.—36,500 LB. PER SQ. IN. TENSILE—ETCHED WITH PICRAL—x100. STRUCTURES OF AUSTENITIC CAST IRONS CONTAINING 14 PER CENT NICKEL, 6 PER CENT COPPER AND 2 PER CENT CHROMIUM.

dendritic. Inoculation reduced or eliminated the surface dendritism and this raised the values of all properties dependent upon surface conditions.

16. The uninoculated high carbon irons, however, were not as susceptible to dendritic graphite formation near the surfaces since they had sufficiently high graphitizing power to perform naturally the function of ladle inoculation and bring about graphitization in the melt; consequently these irons had higher transverse properties than the untreated low carbon irons.

17. In some cases it was noted that an improvement in transverse or impact properties was obtained with little or no effect on tensile strength; this was due to the presence or absence of dendritic structure in the controlling areas of maximum stress.

18. The decrease in hardness of the low silicon low carbon specimens upon inoculation was undoubtedly due to a decrease in combined carbon as indicated in Table 1.

19. It will be recalled that the steel base castings were consistently superior to the scrap heats. No pertinent difference could be found between the microstructures of the two as illustrated by typical examples in Figs. 5 and 7. This would indicate that the

difference in physical properties was probably due to a difference in their respective matrix compositions. It was observed that the combined carbon content of the steel charge heats averaged 0.75 per cent whereas the scrap heats averaged 0.62 per cent. The greater hardness and strength of the former were very likely related to this characteristic.

Machined Transverse Bars

20. Upon observing the very large improvement in those properties dependent upon skin structure, secured by silicon inoculation, one might be led to believe that the results were simply a skin effect. It has been found, however, from tests on 1.2-in. diameter bars machined from oversized bars $1\frac{3}{4}$-in. diameter, that ladle inoculation does improve the flexure properties of 14 per cent nickel, 6 per cent copper, 2 per cent chromium iron castings both at the surface and internally where dendritic structures are eliminated by such treatment.

21. Data substantiating this are shown in Table 3. These heats were made of 50 per cent steel, balance alloy pig and iron scrap. The low carbon heats were made in an induction furnace and the high carbon heats in an indirect arc rocking furnace. It can be seen in the case of the 2.15 per cent carbon irons that the transverse and impact of both the cast to size and the machined bars were improved by inoculation and that the associated surface graphite structures were dendritic in the case of the untreated castings and flake in the inoculated bars.

22. For the 2.70 per cent carbon castings, the cast to size bars were improved with the inoculation but little difference was observed in the machined bars. The latter is as would be expected

Table 4

COMPARISON OF LADLE INOCULATED AUSTENITIC AND HIGH TEST CAST IRON

Iron	Ladle Silicon per cent	Total Carbon per cent	Total Silicon per cent	Transverse* Load lb.	Transverse* Def. in.	Izod AB ft. lb.	Tensile Strength lb. per sq. in.	BHN
Austenitic Iron1	0.0	2.34	1.03	3395	0.120	53	40,400	213
Austenitic Iron1	1.2	2.25	1.70	5230	0.600	2–50	46,600	177
1.0 per cent Ni								
Gray Iron	0.0	3.01	1.77	4655	0.12	22	44,660	241
Gray Iron	0.70	3.00	2.34	5805	0.15	39	58,310	241

* Transverse on a 12-inch span.

1 Austenitic iron contained 14 per cent nickel, 6 per cent copper, and 2 per cent chromium.

since both bars were identical in structure and contained flake graphite.

Austenitic Iron vs. Pearlitic Iron

23. The striking differences in properties between the austenitic and pearlitic irons are the very high flexure properties of the former and the comparatively higher tensile properties of the latter. A comparison of the effects of silicon inoculation on the properties of low carbon austenitic iron and high test nickel gray iron is shown in Table 4. It can be seen that the increase in transverse and impact properties of the austenitic iron is much greater as a result of the ladle treatment than for gray iron. On the other hand, the latter shows a greater increase in tensile strength. These differences are believed due to the inherent qualities of the matrix structures, which are permitted to seek more nearly their true level when the graphite distribution is in the optimum arrangement. Austenite has greater toughness and elongation than pearlite whereas the latter has greater tensile strength.

24. The percentage increase in transverse properties of the austenitic iron was greater than the tensile properties of the gray iron undoubtedly because of an exaggerated surface condition in the untreated austenitic iron resulting from rapid cooling, which would allow more room for improvement.

CONCLUSIONS

25. As a result of this work, the following conclusions may be drawn:

(1) The transverse properties and tensile strength of 2.25 per cent carbon austenitic iron, containing 14 per cent nickel, 6 per cent copper and 2 per cent chromium, were markedly improved by ladle additions of ferro-silicon, whereas, high carbon iron of similar alloy content was only moderately affected. The Izod impact properties of all grades were improved by silicon inoculation.

(2) The improvement in properties was associated with a corresponding change in the microstructure. Low properties existed in irons having a dendritic carbide and graphite arrangement, whereas high quality material possessed a more random distribution of these constituents.

(3) Dendritism was most apt to form in low carbon irons

and at the surface of all castings; therefore, it follows naturally that the elimination of this condition would improve the properties which are dependent upon a good structure in these locations.

(4) Austenitic nickel-copper-chromium cast iron made from charges with high percentages of steel had superior mechanical properties and were improved to a greater extent by inoculation treatments than were castings made from cast iron scrap.

(5) In general the mechanical properties of the inoculated bars decreased as the carbon plus silicon increased.

(6) The austenitic nickel-copper-chromium cast irons possessed outstandingly high toughness and transverse ductility compared to pearlitic gray iron.

ACKNOWLEDGMENTS

26. The author wishes to acknowledge the very able assistance of Messrs. F. G. Sefing, F. B. Rote and L. Seigle in conducting the experimental work.

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DISCUSSION

Presiding: J. T. MACKENZIE, American Cast Iron Pipe Co., Birmingham, Ala.

Co-Chairman: V. A. CROSBY, Climax Molybdenum Co., Detroit, Mich.

MEMBER: What normal carbon would you expect with cupola melting iron?

DR. EASH: About 2½ per cent carbon.

MEMBER: Would you expect the inoculation treatment to have an equal effect on the cupola material in the lower carbon range?

DR. EASH: Yes, it would. We have made cupola heats of this austenitic iron using high steel charges that ran up around 45,000 lb. per sq. in. tensile strength.

Would your discussion follow along the same line when using ordinary cupola iron containing 1 per cent chromium, leaving out the other alloys?

DR. EASH: When chromium is added, it is best to ladle inoculate the iron in order to produce a good graphite structure free of chill. The higher chromium irons are improved in properties when ladle inoculated.

MEMBER: What chromium content are you considering in the austenitic iron?

DR. EASH: 2 per cent chrome.

MEMBER: Do you vary the chrome? Do you have less or more need for inoculation to get improvements?

DR. EASH: The chromium content of the 14 per cent nickel-6 per cent copper iron may be varied from 1.75 to 6 per cent, depending upon the application. The normal grade containing 2 per cent chromium has much better resistance to growth than pearlitic cast irons, and when exceptional heat resistance is required, the chrome may be raised up to 6 per cent. When the chromium is increased the chilling power of the iron is greater and the need for ladle inoculation likewise becomes greater to secure the best properties.

MEMBER: You recommend a 30 per cent nickel iron for certain uses of austenitic iron. What chromium content does this iron have and how does it respond to inoculation?

DR. EASH: The chromium content of the 30 per cent nickel iron is

usually around 3 per cent, although it may vary from 1.5 to 4.5 per cent depending upon the application and the machinability desired. In arbitration bar sections, ladle inoculation has a negligible effect at the low chrome levels; however, at the higher chrome contents, mild improvement is obtained by ladle treatment.

MEMBER: Did you go into the matter of contact time?

DR. EASH: We have not investigated experimentally the effect of contact time after ladle inoculation of the austenitic irons. We have found, however, in the case of plain iron, that the effects of ladle treatment wore off after holding the metal in the ladle about 15 minutes.

F. G. SEFING[1]: I have found that the contact time for austenitic iron is about the same as for plain iron. I had occasion about two years ago to investigate this when 30 lb. ladles were being poured from a 600 lb. electric furnace heat. The time interval was so long that it was necessary to speed up the metal handling because the effect of silicon inoculation was being lost after about 25 minutes.

I would like to make another point on 30 per cent nickel irons made primarily for low expansion properties. The very much higher graphitizing power of this higher nickel content produces the normal graphite flakes in the as-cast condition even without inoculation. One has to go to very low carbon levels, below 2.10 carbon, before encountering enough dendritism to throw low impact properties and to make inoculation necessary.

MEMBER: What is the eutectic carbon with 30 per cent nickel?

DR. EASH: About 2.8 per cent carbon. It is considered that about 20 per cent nickel lowers the eutectic about 1 per cent carbon.

MR. SEFING: I have found that kish will form on 3.08 per cent carbon iron, with normal composition of 14 per cent nickel, 6 per cent copper, 2 per cent chrome. The 30 per cent nickel irons will be very open-grained if the carbon is above 2.5 per cent in ½- to ¾-in. sections.

It all comes back to the fact that there is much higher graphitizing power with these higher nickel contents, and, therefore, the saturation point is reduced and the tendency to throw kish is reached at much lower carbon levels. Openness of the iron is also encountered at much lower carbon levels.

MEMBER: What silicon do you speak of?

MR. SEFING: Two per cent silicon with 14 per cent nickel, 6 per cent copper, or the 20 per cent nickel irons.

MEMBER: What silicon do you use for 30 per cent nickel iron?

MR. SEFING: The silicon level should be about 1½ per cent. In the the same section 1½ per cent silicon would be used for 30 per cent as compared to 2 per cent silicon for the 14 per cent nickel-6 per cent copper iron.

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[1] International Nickel Co., New York, N. Y.

A Sand Control Program in a Mechanized Malleable Foundry

By D. F. Sawtelle*, Branford, Conn.

Abstract

This paper is a further report of progress in sand control in an old malleable foundry which modernized its technique by the installation of a duplex melting system and the necessary mechanical equipment for continuous melting, sand preparation, molding, and pouring. It is a continuation of the author's previous paper which dealt with the use and control of natural bonded molding sands, and was presented before the annual convention of the American Foundrymen's Association in 1940.

1. To obtain a clear picture of the problems of sand control in any one foundry, it is essential to know the mechanical equipment which it uses.

2. Back in the old days, a molder took care of his own sand pile with only a shovel, or perhaps a shovel and a riddle, for equipment. In more recent years, sand cutters, aerators or blenders, and mullers, either singly or in combination with each other, have come into common use.

3. As more and more of the control and conditioning of the sand was taken away from the molders, it became increasingly necessary that some one person should assume this new responsibility. Most foundries found someone in their organizations willing to pioneer in this new field of testing and controlling the properties of molding sand.

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* Metallurgist, Malleable Iron Fittings Co.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

EQUIPMENT PRIOR TO JUNE 1941

4. The only mechanical sand conditioning equipment in use by the Malleable Iron Fittings Co. in the malleable* foundry, prior to June 1941, comprised two sand cutters, one aerator, and a muller. The sand cutters were used each night to cut over and pile up about eighty molders' sand heaps. The muller and the aerator were used during the day to mix 5 different grades of facing sand. Fig. 1 is a typical view of the molding floors in a foundry of this unmodernized type.

DESCRIPTION OF THE NEW FOUNDRY

5. Plans for a mechanized malleable foundry were well under way early in 1940, and on June 23, 1941 the equipment was in full operation.

FIG. 1—MOLDING FLOORS PRIOR TO FOUNDRY MECHANIZATION

6. Fig. 2 is a schematic diagram or flow sheet of this new foundry. The melting is done in either of two cupolas; the refining and super-heating in a pulverized, coal-fired, air-furnace.

7. The sand from an overhead storage bin of 100 tons capacity is let down in measured batches of 2200 lb. into either of two mul-

* This company also operates a steel foundry.

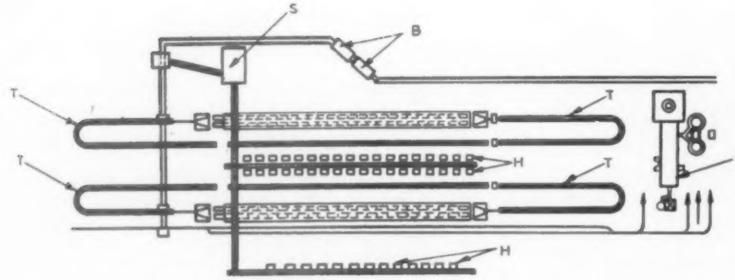

FIG. 2—DIAGRAM OF NEW MECHANIZED FOUNDRY—(M) MELTING UNIT, (T) TRAINS, (H) MOLDERS' SAND HOPPERS, (S) SAND STORAGE BIN, (B) SPRUING AND CLEANING BARRELS

lers (Fig. 3), where the proper amounts of water, sea coal, and clay binder are added.

8. After the batch is mixed, it is dumped by gravity onto rubber belt conveyors which take it for distribution to any of the 50 individual molders' hoppers, shown in Figs. 4 and 5. The molder, by means of a lever and a tilting chute as shown in Fig. 6, controls the flow of sand to his flask as needed.

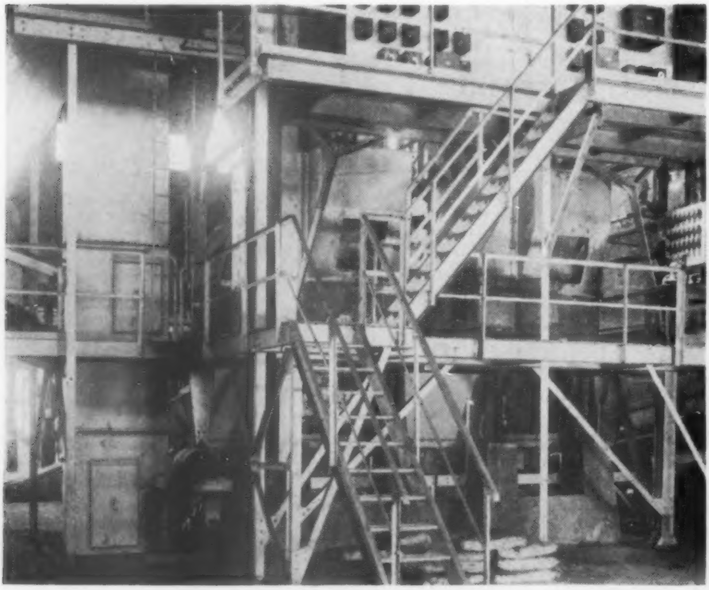

FIG. 3—MULLERS AT SAND RE-BONDING STATION

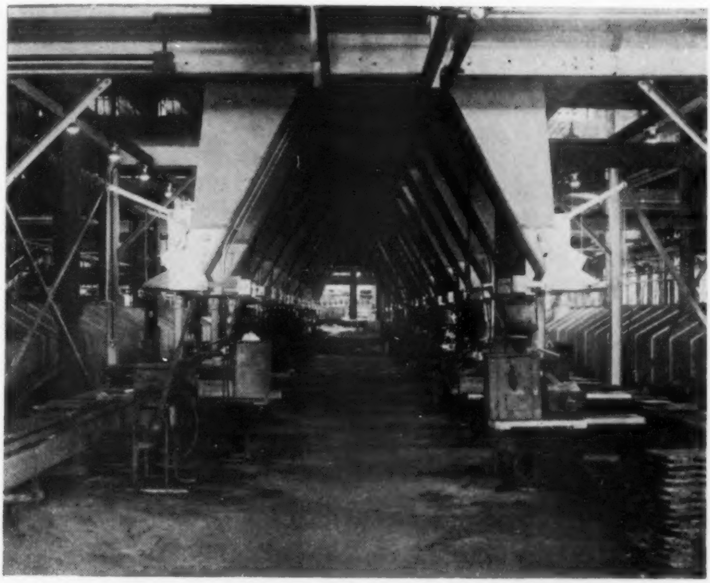

FIG. 4—MOLDERS' SAND HOPPERS—TWO ROWS OF 18 EACH

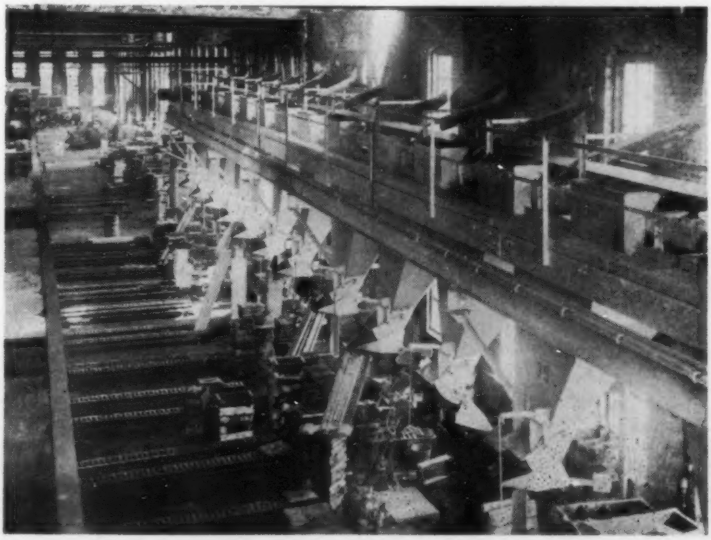

FIG. 5—MOLDERS' SAND HOPPERS—"SOUTH FLOORS"

9. The molds are placed on trains which operate on an indexing system; that is, they automatically go and stop at definite intervals at their proper stations. A train which has been at the molders' station for four and one-half minutes is loaded with molds and then conveyed to the pouring floor, where it again stops.

10. After the molds are poured, they move through cooling chambers and thence to the dumping stations which are shown in

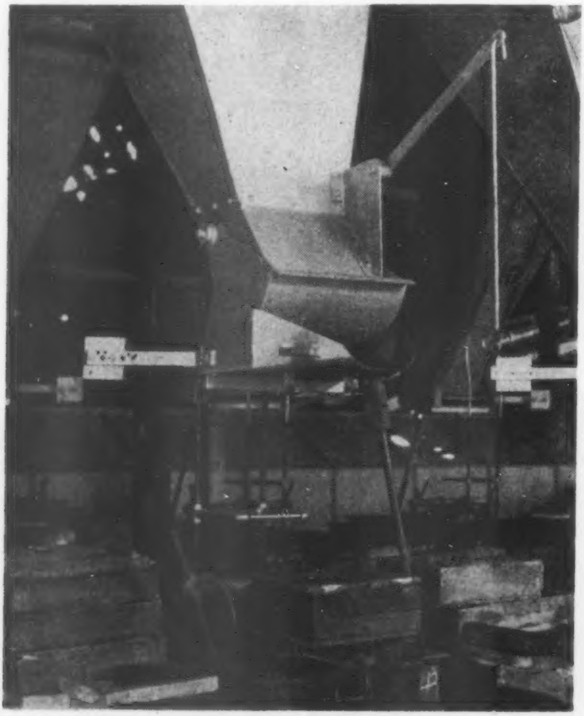

FIG. 6—CLOSE-UP VIEW OF MOLDERS' SAND HOPPER

Fig. 7. Here they are dumped on a steel cross-conveyor which takes the hot castings, used molding sand, and burnt cores, to a vibrating screen. The molding sand and burnt cores are broken up and pass through the screen onto a conveyor, which carries them over a magnetic separator and then to a bucket elevator. The sand is then elevated to a final rotary screen at the inlet to the main storage bin, and this action completes the cycle of sand handling.

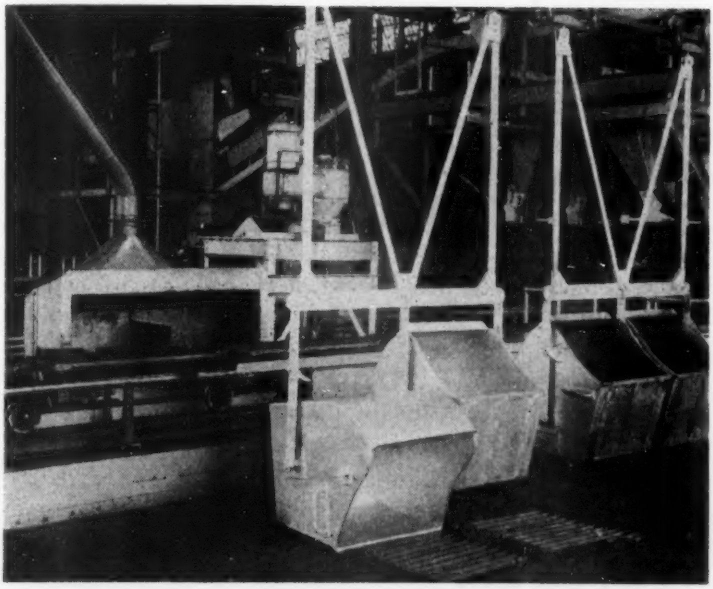

FIG. 7—DUMPING STATIONS FOR POURED MOLDS—"SOUTH FLOOR" MOLDS IN FOREGROUND, "LOOP" MOLDS IN LEFT CENTER

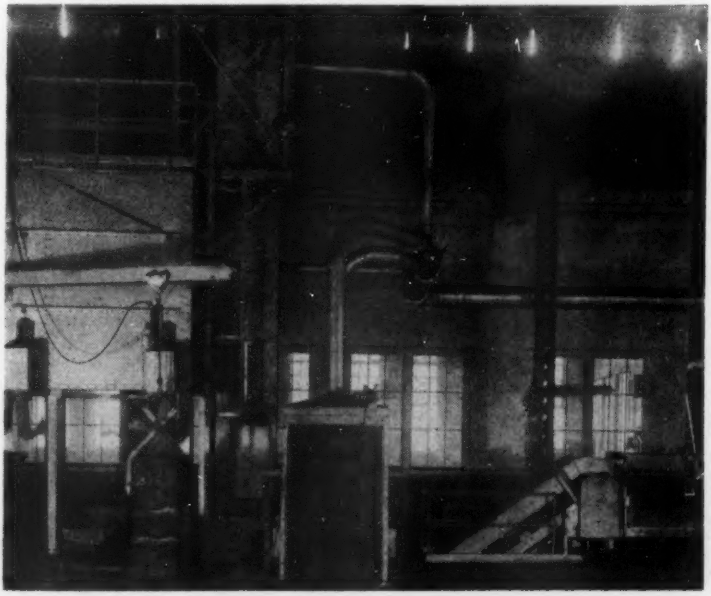

FIG. 8—ANNEALING POT PACKING AND DUMPING STATION

11. The castings proceed either to a hand spruing station, or directly to a wet spruing and cleaning barrel, according to their type and adaptability to this form of treatment. From these spruing operations, the sprue and the castings travel along on belt conveyors to a station near the cupolas where the sprue is picked off for remelting. The castings then proceed to the inspection room.

12. At the point of inspection, the good castings are moved in pans on roller conveyors to an annealing-pot loading and dumping station. In Fig. 8 this dumping station is shown in the front foreground, and the inspection room in the background.

STAGE BY STAGE METHOD OF PUTTING NEW FOUNDRY INTO OPERATION

13. This pot loading and dumping station which may be considered as the end of the line, was erected and put into operation first. At this station, a view of which is seen in Fig. 8, a tier of four pots, after anneal, is stripped of its castings and packing over a vibrating shake-out. The packing material passes through the screen to a bucket elevator, then to a set of screens over a storage bin, which remove the oversize and undersize material. The tier of empty annealing pots is now moved just a few feet to the packing station and hard castings are packed with screened, dust-free, packing material from the overhead storage bin.

14. The wet spruing and cleaning barrel, and the conveyors connecting it with the inspection room, was the next unit to be put in operation. At first this unit was fed by hand with castings from the No. 1 foundry molding floors, where melting in a batch-type air furnace went on all through the change-over period.

15. Next the cross-conveyor, connecting the shake-out stations and the vibrating screen, was put into operation.

16. Then the cupolas, now moved to their new locations, but not yet connected to the duplex furnace, were used to melt cupola malleable iron. The erection of the mold conveyor was the next step taken in the installation, and then the cupola malleable iron was poured into a few trial molds on the train conveyors while the indexing system was adjusted. This left the duplexing of the iron from the cupola through the air furnace as the only remaining link in the chain.

Table 1

Removal of Pan Material from Stock Sand

Test No. and Sand Type	Per Cent Remaining on Screen No. 5										Per Cent		
	12, 20	30	40	50	70	100	140	200	270	Pan	Clay A.F.A.	Grain A.F.A.	Total Carbon
1 Heap & Cores	1.78	3.56	5.70	5.74	14.14	23.56	22.60	11.14	4.34	4.96	2.48	93	—
2 Heap	0.21	0.20	0.48	1.62	3.74	23.76	23.01	14.52	7.09	11.09	14.28	129	—
3 Wareham	1.02	0.98	2.28	6.72	21.08	29.12	23.84	10.04	2.88	2.00	—	72	—
4 Providence	—	0.04	0.07	0.38	2.30	12.09	24.80	25.05	13.21	20.51	1.55	160	—
5 Jersey No. 52	8.16	36.56	47.24	6.68	0.66	0.46	0.22	—	—	—	—	23	—
6 Synthetic (18*)	1.18	2.80	4.48	4.82	12.96	21.18	21.92	12.30	4.52	5.12	8.72	97	1.44
7 Synthetic (54*)	1.04	3.88	6.34	5.46	15.74	24.48	21.38	9.16	2.34	1.80	8.38	81	2.48
8 Synthetic (78*)	1.18	3.60	5.06	4.38	13.00	22.38	22.90	13.26	4.42	3.78	6.04	93	0.97
9 Synthetic (126*)	1.72	5.82	7.10	5.08	14.08	23.90	23.02	8.86	2.36	1.30	6.76	79	2.08
10 Synthetic (158*)	1.26	4.38	6.14	4.82	14.60	25.30	23.64	9.10	2.42	1.54	6.80	81	2.21
11 Dust Separator Sludge	0.06	0.06	0.12	0.20	0.78	2.64	10.98	26.30	21.60	33.34	3.92	202	5.05

* Number of days of operation when sample was taken.

17. On June 23, 1941, this last step was taken, and the foundry was put in complete operation as thirty tons of metal were melted and poured.

TYPE OF SAND IN STORAGE BIN FOR FIRST TRIALS

18. As has been previously stated, the castings were taken from No. 1 foundry and included the adhering burnt molding and core sand. This sand accumulated in the main storage bin and was the source of the first synthetic molding sand trials.

19. Table 1 shows the screen tests of this sand in test 1. It is a mixture of the adhering heap sand as shown in test 2 and the three different core sands which are shown in tests 3, 4 and 5.

20. This varied mixture of sands was mulled with sufficient water and a southern bentonite bond to give a molding sand of the following properties: Moisture, 4.5 to 5 per cent; Permeability, 40 to 50 per cent; Green strength, 7 to 9 per cent. These values were not obtained on every batch, as during these trial mixes an inexperienced man was being broken in to operate the mullers.

21. Moisture testing apparatus was placed conveniently so that for the first few days the operator tested every batch for moisture which taught him the "feel" of the sand in a very short time.

22. Observing the results obtained by the molders, who were given chances to try out the new over-head supply of sand, it soon became apparent that moisture down to 4.5 per cent and strength as high as 9.0 per cent gave us a sand with which it was possible to obtain good molds, and gave castings with a fair finish.

TYPE OF SAND IN STORAGE BIN ON FIRST COMPLETE OPERATING DAY

23. The main sand storage bin was filled in readiness for the first day of full operation. It contained sand from the individual sand heaps in the old foundry which has been referred to before as sand No. 2 in Table 1. These heaps were mostly of Albany sand, to which had been intentionally added about 10 per cent of a strong New Jersey sand, and, unintentionally, a smaller percentage of burnt core sand.

24. At this point it is important to note that the pan material tested 11.09 per cent, and the total per cent on the 6, 12, 20, 30 and 40 screens, was less than 1.00 per cent.

Core Sand Additions to Stock Sand and Its Effect

25. Our type of malleable castings require the use of approximately one ton of cores to every 7.5 tons of metal poured. In shaking-out the poured molds, nearly all of the burnt cores are each day incorporated with the stock of sand in the system. The stock sand, therefore, eventually assumes many of the characteristics of the core sands used. These core sands, which have previously been referred to in Table 1, are used in the proportion of 55 per cent Wareham, 40 per cent Providence river, and 5 per cent of the New Jersey No. 52.

26. This accounts for the marked rise in the percentages of sand on screens 6, 12, 20, 30, 40, 50 and 70 in tests No. 6, 7, 8, 9 and 10 of Table 1, in comparison with the amounts on the same screens in test 2 which represents the heap sands loaded into the system at the start.

Effect of Rotoclone Dust Separator

27. The important part played by a dust separator in the operation of this mechanized foundry must be explained in order to understand the changes in the sand which it causes.

28. Connected to the dust separator and, hence, under suction, are the cooling chambers, mold dumping stations, cross-conveyors, shake-out screens, top screen (above the sand storage bin), mullers, and the aerator which is in line with the main sand distribution belt.

29. This dust separator "hook-up" has three important effects on foundry operation. First, it removes the greater part of all dust and smoke caused by usual foundry operation. Second, it is absolutely essential in its cooling action on both poured castings and the resulting hot molding sand. Its third effect is the removal of nearly all the pan material from the stock sand, as may be seen in Table 1.

30. It should be noted that after only 18 operating days (test No. 6), the percentage of pan material had dropped from 11.09 per cent, as in the original heap sand, to 5.12 per cent, and after 54 operating days, to 1.80 per cent. A screen test of material collected in the dust separator is shown in test No. 11 of Table 1. For a more vivid illustration, results were obtained from a visual test by putting the sand from these two screen tests into racks of test tubes and placing one over the other as in Fig. 9. The first

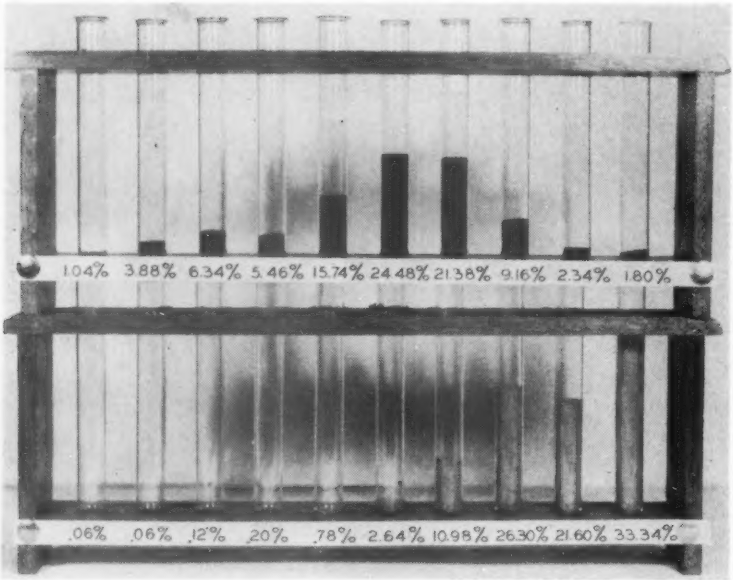

FIG. 9—SAND FROM SCREEN TESTS NO. 7 AND 11 OF TABLE 1

test tube on the left contains all the sand on the 6, 12 and 20 mesh screens, the sand on the 30, 40, 50, 70, 100, 140, 200 and 270 mesh screens, and the material on the pan being arranged in order reading from left to right.

PROBLEM OF EXCESSIVE LOSS OF FINES AND BUILD UP OF COARSE PERCENTAGES

31. Long before the new foundry went into operation it was realized that the type of core sands in use would become the base of the eventual molding sand, and that it would necessarily be much coarser than the natural bonded molding sands which had been used in the past.

32. It would have been impossible for the core shop, which makes the larger percentage of its cores with blowing machines, to operate on any one particular grade of sand which might have been chosen as an ideal base for molding sand. This is because of the delicate balance required between the air vents in the core boxes and the type of sand used, when blowing cores at high speed. Any drastic change in core sands would have entirely disrupted production. Therefore, it was decided to use the same core sands but to

gradually increase the amount of the finer Providence river sand, and decrease the coarser Wareham, and especially the No. 52 New Jersey. The core shop is still working in this direction but with caution.

33. The amount of fine removal could not be estimated, but only arrived at by actual operation. The author has never believed that fine removal from molding sand should be carried too far in the malleable foundry. Test No. 6, Table 1, showing the pan material down to 5.12 per cent, after only 18 days of operation, was the first guiding indication, and test No. 7, after 54 operating days, showed the extent of this fine removal, there being only 1.80 per cent pan material left. Adverse conditions arising from this low amount of fines are poorer casting finish and quicker drying out of the molding sand. The addition of Providence river sand to raise the percentage of fines was tried for a short time and accounts for the 3.78 per cent pan material obtained on test No. 8.

34. The most ideal way to cure the condition of excessive fine removal would be to put back into the sand system the material taken out by the dust separator; and this is being worked out at the present writing, though it is not a simple problem.

Sea Coal in the Stock Sand

35. When the sand from the molders' old sand heaps was originally stored in the sand bin it contained only a small amount of sea coal. This came from the use of facing sands. In the new system, the operation of the mold shake-out screen, the magnetic separator, and a revolving screen over the top of the storage bin result in such a clean sand that, with the addition of sea coal, it can be considered a facing sand. The amount of sea coal added to the sand is controlled by analyzing for total carbon. These results have been included in the screen tests in Table 1.

36. As may be seen from Table 1, after 18 operating days, the carbon was 1.44 per cent. This increased until the 54th operating day when it had reached 2.48 per cent, at which point it was decided to cut back on the amount added and attempt to keep it in the neighborhood of 2.00 per cent to 2.25 per cent. Test No. 4, with 0.97 per cent carbon, may be ignored as it was taken when considerable amounts of Providence river sand were being added to increase the fines.

37. The cleanliness of the sand and the addition of this amount

Table 2

OLD PRACTICE—COST OF NATURAL MOLDING SAND, CORE SAND, SEA COAL TO TONS OF METAL POURED

	Tons of Mold. Sand	*Cost of Mold. Sand*	*Tons of Sea Coal*	*Cost of Sea Coal*	*Tons of Core Sand*	*Cost of Core Sand*	*Total Cost Sands & Coal*	*Tons of Metal Poured*
1939	2,041	$8,368	50	$800	1,471	$4,161	$13,329	11,258
1940	2,276	9,332	25	400	1,204	4,376	14,108	10,106
2 Yrs.	4,317	$17,700*	75	$1,200	2,675	$8,537	$27,437	21,364

NEW PRACTICE—COST OF BENTONITE BOND, CORE SAND, SEA COAL TO TONS OF METAL POURED

	Tons of Bond	*Cost of Bond*	*Tons of Sea Coal*	*Cost of Sea Coal*	*Tons of Core Sand*	*Cost of Core Sand*	*Total Cost Sand Bond Coal*	*Tons of Metal Poured*
7 Mos.	130	$2,860	75	$1,200	1,090	$3,488	$7,548	8,721

* Costs of all material are delivered costs.

of sea coal to it, gives a much better finish to the castings than would be expected from the grain distributions shown.

MOISTURE, PERMEABILITY AND GREEN COMPRESSION STRENGTH

38. Sufficient bentonite bond is added to keep the green compression strength of the sand between 7.0 and 8.0 lb. The moisture content has been lowered as the percentage of fines has decreased. The moisture at first was between 4.5 and 5.0 per cent, decreasing to 4.0 to 4.5 per cent, and finally to 3.5 to 4.0 per cent. As the fines and moisture became less, the permeability became greater, rising from 35 to 45 to 45 to 55, and becoming quite constant, being between 55 and 65 at the present time.

COST OF NATURAL BONDED SANDS VS. SYNTHETIC

39. Figures indicating the tons of new, natural-bonded molding sand, core sand, sea coal used, and their cost for the years 1939-1940 and the tons of metal poured are given in Table 2, and likewise the tons and cost of bonding material, sea coal, and core sand, during the first seven months operation of the new mechanized foundry.

40. From this table it may be calculated that the cost of these materials during 1939-1940 was $1.28 per ton of metal poured and for the first seven months of mechanized operation was $.86 per ton of metal poured.

DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

MEMBER: In making molds, such as you make, what do you consider a proper percentage of fines?

MR. SAWTELLE: I like to keep 5 per cent of pan material in our sand. Several years ago, before we even specified what type of sand we wanted, a screen test of the Albany sand showed 30 per cent pan material. By specifying the grade of Albany sand that we wanted, that percentage was reduced to about 15 per cent. With this set-up it is possible to take all of the fines out, if desired.

MEMBER: Is it possible to control the fines in molding sand by the use of the correct bond? From past experience, we find that various bonds act differently and each one has an effect on the way the sand will react and on the percentage of fines.

MR. SAWTELLE: Our dust removal system works under such a high suction that I cannot believe that a different type of clay would have much to do with how much or how little of the fines the collector removed.

MEMBER: Does not your muller increase the fines to some extent, regardless of the dust collector?

MR. SAWTELLE: I do not think the muller raises the percentage of fines much. The sand is in the muller only about 3 min. as an average and it is not a grinding action. It is a mixing action.

F. L. HARRIS[1]: We ran some tests and found that the mulling has no effect on the fines; that is, no effect that can be appreciably calculated. We have found that there is no destruction of the grain by mulling.

Do you expect to eventually have a sand in the foundry comparable to the base sand used in the core work? In other words, if good results are secured with 15 per cent fines in the Albany sand being used, and I gather that the sand now being used carries about 2 per cent of fines, it will be necessary to regulate the amount of fines by using suction only to the point where the sea coal and clay builds up over the 15 per cent fines. I agree that a certain amount of fines in the sand is desirable. Complete elimination of the fines is not the best practice.

MR. SAWTELLE: I have never measured the height of the vacuum in our dust collecting apparatus. It is a wet collector with a very high vacuum. It is necessary in many places due to its cooling action on both the sand and metal. The vacuum is so high, though, that no matter what type of core sands is used, it will take the fines down to too low a point. We are mixing Providence River with the Wareham, which has a considerable amount of fines, and still our storage sand is down around 1.8 per cent.

MR. HARRIS: In our plant we finally wound up with practically the same sieve analysis as our core sand. After it has been established for a period of several years, I think you will find that you eventually wind up with the same screen analysis for the sand in the foundry as for the core sand going into the foundry.

MR. SAWTELLE: I went through several pages of calculations in simple arithmetic, using the proportions of the core sands as we use them, and the percentages one would expect on the different screens. If I could have put in a correction factor for the amount of fines removed, I believe the screen test would have been as was calculated, even after only 54 operating days.

[1] Belle City Malleable Iron Co., Racine, Wis.

The Use of Job Evaluation in the Application of Time Study

By E. L. Berry* and E. A. Berg*, Chicago, Ill.

Abstract

Establishing a basis for a sound wage policy requires the analysis of two factors, (1) hourly base rates in proportion to skill and technique, and (2) incentive plan to reward employees. In discussing these problems the authors give their methods for establishing wage payment levels, describe their occupational rating plan and review factors in the correlation of minimum and maximum average hourly rates. They then discuss their incentive plan, emphasizing the use of elemental time studies.

1. The principal aim of both time study and job evaluation is to fulfil the need for an adequate method to reward the employee in his weekly pay check commensurate to the talent and effort expended. His satisfaction is in direct proportion to the wage payment policies set up by the management.

Basis for Sound Wage Policy

2. The basis for a sound wage policy requires the analysis of two factors:

A. Evaluate and set up a plan for adjusting the hourly base rates in proportion to the skill and techniques required to perform the individual occupation. The ignoring of this fundamental principle can only lead to dissatisfaction on the part of the worker.

B. Establish an incentive plan to reward employees who use

* Vice President and Head of Wage Incentive Department, respectively, Link-Belt Company.

Note: This paper was presented at the Job Evaluation and Time Study Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

their efforts and technique to their ablest degree.

The type of incentive plan used should be readily understood by the employees, and payment must be made in direct proportion to the work accomplished. Policies abolishing the "cutting" of rates should be established, and rigidly adhered to, except in cases wherein a change in method of manufacture is involved. If the above factors are installed and applied correctly, the results can only lead to mutual benefits for both labor and management.

WAGE PAYMENT LEVELS

3. To establish the correct wage payment levels for the various occupations, management must take the following steps:

A. Choose an accepted rating plan, which will account for all characteristics and limitations of each and every occupation. Each fundamental characteristic which affects the job, such as skill, effort, conditions, etc., must be considered and graded in order to obtain a differential between the various occupations.

B. Evaluate each occupation with the assistance of the general foreman and the immediate supervisor of the department whose occupations are being classified. In this manner, the supervisor becomes thoroughly acquainted with the plan, and will contribute detailed information which is necessary for the accurate classification of each job.

C. List values of each characteristic on a comparison sheet in order to determine the consistency of the evaluations. Any discrepancies in ratings will appear instantly when entered on this tabular sheet.

D. Use wage surveys to correlate wages with evaluated point ratings, and plot a curve to obtain the theoretical average wage level for each occupation. This is an important step and care should be taken to ascertain the prevailing wage levels accurately, in order to keep wages in line with existing levels throughout the territory or community. It may also be noted that occupations having the same total point-rating, irrespective of the department, will fall in the same wage range.

E. Plot the actual existing hourly wages on the above graph to obtain a complete picture of the present wage structure in respect to the theoretical curve. This will readily bring to light occupa-

tions that are not at their proper wage level.

F. Using the theoretical average wage curve (See D) as a basis, establish minimum, maximum, hiring, and incentive wage levels.

G. Establish and maintain records which contain the basis for evaluation and comparisons between different occupational ratings.

H. Correct the existing hourly rates to conform with the evaluated levels. This must be a gradual transition, otherwise the plan will appear too radical, and fail before it has been properly installed.

OCCUPATIONAL RATING PLANS

4. A brief description of one of the better occupational rating plans, originated by A. L. Kress, will serve to clarify the foregoing information.

Eleven Factors

5. This plan considers 11 factors which constitute the principal requirements for any occupation.

(1) Education
(2) Experience
(3) Initiative and ingenuity
(4) Physical demand
(5) Mental or visual demand
(6) Responsibility for equipment or process
(7) Responsibility for material or product
(8) Responsibility for safety of others
(9) Responsibility for work of others
(10) Working conditions
(11) Unavoidable hazards

6. These factors have been divided into five degrees and point values assigned to each. Thus with the aid of an accurate description for each factor and degree, all occupations can now be evaluated in terms of point-ratings.

Example—Class B Bench Coremaker

7. For example, the occupational rating for a *Class B Bench Coremaker* should be something like this:

		Point Values	*Degree*
(1)	Education	14	1st
(2)	Experience	44	2nd
(3)	Initiative	28	2nd
(4)	Physical demand	30	3rd
(5)	Visual demand	15	3rd
(6)	Resp. for Equipment	10	2nd
(7)	Resp. for Product	10	2nd
(8)	Resp. for Safety of others	15	3rd
(9)	Resp. for Work of others	5	1st
(10)	Working conditions	30	3rd
(11)	Unavoidable hazards	15	3rd

8. All other occupations are classified in the same manner, and comparisons are made to check the consistency of each rating.

CORRELATION OF MINIMUM AND MAXIMUM AVERAGE HOURLY RATES

9. If the plant consists of a foundry and pattern shop only, we will find that pattern makers head the point-rating list while laborers will appear in the lowest bracket, as is to be expected. However, we now have a definite ratio for all other occupations falling between these two. Hence, if accurate wage surveys are made for both pattern makers and laborers, we can now correlate minimum and maximum average hourly rates for all occupations by merely plotting the survey earnings for the high and low occupations against their point-ratings. As a check, the average hourly earnings for the average point-rating are also plotted. A curve is then plotted through these three points.

10. The existing hourly wages are then plotted, and the minimum and maximum wage range bands determined (Fig. 1). These bands are usually on plus and minus percentages in relation to the average hourly earning curve. The percentage values are determined to some extent by the existing hourly wage structure. The minimum hiring rate is usually located somewhat below the minimum wage level. The gradual correction of hourly rates is then made, taking care not to make any extreme changes in either direction.

11. Thus, management has now determined wage levels which will assure a fair share of the available supply of both skilled and unskilled labor in the territory, plus a method of determining payment in harmony with the individual occupations. An incentive to further increase the workers' individual capacities will be created by the use of this scheme.

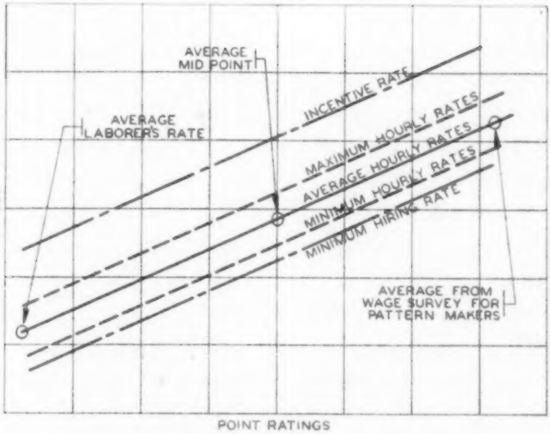

FIG. 1—CHART SHOWING METHOD OF CORRELATING WAGES WITH POINT RATING.

INCENTIVE PLAN

12. To maintain this system, however, and permit the operators to earn wages in proportion to their effort and capabilities, some type of incentive plan should be established. Such a plan must embody certain characteristics to insure adequate results for both labor and management.

13. The elements of any successful incentive plan will include:

A. Standardization of equipment and methods. This means all flask bands, flask equipment, patterns, etc., must be in good repair. Core boxes must be accurate to produce a correct size core. Laborers must provide operators with all material and equipment such as flasks, patterns, cores, bands, sand, etc., in order that the men may stay within their working area. This must be accomplished before any time studies are undertaken. However, in the case of jobbing foundries, there is an economical point beyond which further standardization yields little, if any, dividends, hence, the time study department must not wait too long before standards are established.

B. Establish equitable time standards for elemental operations, with the aid of motion study. Each elemental operation must be analyzed and motion paths established before time standards for each operation can be effected. The time values thus obtained must be leveled to compensate for skill, effort, etc., shown by the operators.

C. All time standards should be combined or condensed into charts, formulas, graphs, or even slide rules, to simplify and standardize methods of establishing incentive rates. Also, methods of recording information should be complete and concise.

D. The method of payment must be in a simple form that is easily understood by the employees. Complex payment schemes lead to distrust, and finally to oblivion.

E. Men in the time study department should be motion minded and familiar with work of the time study department as well as with foundry practices and procedures.

14. Figure 2 shows a comparison of an ordinary time study against a synthetic time study, built up from elemental time standards for a large molding machine.

FORM O.R.I

LINK-BELT COMPANY SHEET NO. 1 OF 2 SHEETS

GENERAL TIME STUDY OBSERVATION SHEET DATE ________ 19__

OBSERVER'S NAME F. K. MACHINE NO. LARGE PNEUMATIC STUDIED BY ________

WORKMAN'S NAME 1083 - 1109 - 1172 OPERATION MOLDING MACHINE COMPUTED BY ________

PATT. NO. CR 213 SUPERVISOR OK ________

DWG. NO. C 178 FOREMAN OK ________

DESCRIPTION C.S. STEERING BRAKE DRUM - 22" DIA. x 4¾" FACE GEN. FOREMAN OK ________

PART MEMBER OF 32" DIA. FLASK - 5¾" DRAW SUPERINTENDENT OK ________

ELEMENTAL OPERATIONS DRAG	Continuous Time	Elemental Time	Standard Elemental Time
FLASK TO PATT. - PINS IN	.60	.60	.45
PARTING	.72	.12	.07
RIDDLE FACING - 3 SCOOPS	1.65	.93	1.14
FILL	1.88	.23	.14
BUMP TWICE AND LEVEL	2.18	.30	.26
PINS OUT	2.26	.08	.05
STRIKE OFF	2.37	.11	.20
LEVEL	2.58	.21	.13
BOARD ON	2.66	.08	.10
SET CLAMP BAR	2.78	.12	.12
CLAMP AND ROLL	2.98	.20	.23
DRAW PATTERN	3.81	.83	.36
MACHINE TO POSITION	3.89	.08	.08
		3.89	3.32

LEVELING FACTOR											
SKILL	%	V	EFFORT	%	V	CONDITIONS	%	V	CONSISTENCY	%	V
A Super			A Super			A Ideal			A Perfect		
B Excellent			B Excellent			B Excellent			B Excellent		
C Good			C Good			C Good			C Good		
D Average			D Average			D Average			D Average		
E Fair			E Fair			E Fair			E Fair		
F Poor			F Poor			F Poor			F Poor		

PREP. ________
RATE SET
EACH ________

MINN. HAND. TIME 3.32
+ .24 % .80
MINN. MACH. TIME ________
+ ____ % ________
TOTAL TIME MIN. 4.12
HRS. .0685
INCENTIVE ________
____
TIME STUDY NO. ________

FIG. 2—TYPICAL TIME STUDY OBSERVATION SHEET SHOWING STUDY OF OPERATION OF MOLDING A CAST STEEL BRAKE DRUM ON MOLDING MACHINE. (TIME STUDY TAKEN TO CHECK MOLDING PROCEDURE. INCENTIVE RATE ESTABLISHED FROM ELEMENTAL STANDARDS. FIGURES ENCLOSED IN BLACK LINE ARE CONTINUOUS TIME FIGURES.)

USE OF ELEMENTAL TIME STANDARDS

15. The only accurate and reliable method of determining incentive rates is through the use of elemental time standards, rather than by taking isolated time studies at random whenever the occasion demands. Isolated time studies invariably lead to inconsistencies in earnings, and are expensive, whereas synthetic studies promote an accurate and consistent rate structure at a much reduced cost.

CONCLUSION

16. To conclude, while the occupational rating plan establishes wage earning levels for the various occupations, there remains for the time study department the job of establishing accurate, equitable incentive rates that will maintain earnings in their desired levels to obtain full benefit of the system. If the incentive plan is established incorrectly, permitting a wide fluctuation of earnings, the job-rating plan will be of little avail.

DISCUSSION

Presiding: F. E. WARTGOW, American Steel Foundries, East Chicago, Ind.

Co-Chairman: JEFF. ALAN WESTOVER, Dyer Engineers, Inc., Cleveland, O.

MEMBER: How do you handle the difference in rate, or the difference in wage level, between an inexperienced man and a man who has been working on a piece rate for 90 days?

MR. BERRY: There are two answers to that. One is that a wage schedule is set on a job that has been defined. A man who has been doing that job efficiently for 20 years gets a rate. If another man has been doing the job for one year and is not quite as efficient, the union states that those are like jobs and the second man gets the same rate. The other answer is that men are not so homogeneous as to be deserving of a common rate under a common job value. That is the reason we have the plus 10 and minus 10 which gives a 20 per cent spread.

MEMBER: If a new molder, with or without experience, is hired, is the piece rate exactly the same as that of the man who has been there a year or who might have the very highest merit rating?

MR. BERRY: There is no differential in the piece rate. The new molder may be getting 30 or 40 cents an hour less than the old-time skilled artisan. It is quite improbable that he will make better than his day rate at first. If he is potentially a skillful man and learns the environment and the run of the shop, he will very rapidly begin to make some bonus. It is quite doubtful if he will ever reach the maximum. We aim at 27

per cent average bonus earnings while working on piece work. We have people who make 10 per cent, and if they are not capable of making more we try not to keep them on the job too long. We have other men who make 70 per cent, and we wish we had more of them. The basic fact is that we have a standard rate for a standard job under standard conditions.

MEMBER: Does your merit rating system apply only to day workers?

MR. BERRY: The merit rating applies to anyone in the plant and ties in with job values. People who have set up merit ratings will give their plant averages, with a maximum merit rating of 90 or 100. If that is so then they have done a poor job in evaluating an individual. It is well known that an average or mean between 70 and 80 of a shop of one hundred or one thousand people is an excellent merit rating for your whole plant. If a man's merit rating is down around 60 per cent or 60 points, it is quite improbable that he will get a raise. If it is up around 78 or 85 per cent, it is quite probable that he will get one.

I mentioned very briefly that job rating and merit rating must be tied into the pay roll. In this connection, we have a suggested wage increase slip on which appears the man's name, the job he is doing, the job value, the minimum and maximum range of payment for that job, and his merit rating. The man is getting $1 an hour. The foreman suggests that he get $1.10 an hour. His rate range from job values might be 95 cents to $1.20. If his merit rating is well up or even average, he is entitled to a day rate change, but the piece rate stays the same until either economic conditions or manufacturing conditions change. The merit rating, tied up with job rating, is simply used to properly determine whether or not that man is worthy of more money. His merit rating card will indicate that, so it is only necessary to check his existing rate and the suggested rate for the top and bottom job values against his merit rating.

MEMBER: Does the merit rating benefit him only on the day rate basis?

MR. BERRY: Yes.

MEMBER: On the piece rating, do you assume that, if his merit rating is high, he will normally earn higher wages?

MR. BERRY: That will follow, if his merit rating is high.

MEMBER: Have you had objections from the union on this merit rating plan?

MR. BERRY: We have no union.

CHAIRMAN WARTGOW: We do not have merit rating. We do not rate the man, we rate the job. In the case of the coremaker, we have A, B and C coremaking jobs. When a man comes into the plant he is hired as a laborer for we do not hire anybody as a skilled operator. When he goes to a job, he takes the rate of pay assigned to it. There is no difference on piece work. The rate is the same for the A, B or C occupation after the job is rated, and a man who has earned an A rating, working on a job that is rated as a C job, takes that rate of pay.

MEMBER: Does it present problems when you hire an experienced molder as a common laborer?

CHAIRMAN WARTGOW: We have lost a few good men, but that is our

agreement with our committee. We try to explain it to the man when he comes to the gate, and I doubt if we have lost very many.

CO-CHAIRMAN WESTOVER: Mr. Wartgow, are you using a piece-work rate expressed in time or in dollars and cents?

CHAIRMAN WARTGOW: In dollars and cents.

CO-CHAIRMAN WESTOVER: Are you also expressing your rates in dollars and cents, Mr. Berry?

MR. BERRY: Yes.

CO-CHAIRMAN WESTOVER: There is that point to be kept in mind. Some of us may be thinking in terms of time, as piece-work rates, and using the base rate to multiply the time piece rate by.

JOHN Z. LUBENKOV[1]: Mr. Wartgow, if a man came into your plant and said he was a skilled man, don't you think it would be fair to take his word for it and let him prove otherwise, rather than put him on as a common laborer?

CHAIRMAN WARTGOW: We do not take his word for it. We put him on the job to see if he can do it.

MR. LUBENKOV: Then you are not putting him on as a laborer.

CHAIRMAN WARTGOW: We hire him as a laborer and bring him into the plant. If there is an opening, he can go to that job.

MR. LUBENKOV: Do you not give him a chance at the particular job he asks for?

CHAIRMAN WARTGOW: We cannot. That is our agreement with our shop committee.

MR. LUBENKOV: Is yours a union shop?

CHAIRMAN WARTGOW: Yes.

MEMBER: Do you make your own patterns or merely buy and maintain them?

CHAIRMAN WARTGOW: We make some patterns and buy others. But when the men come in the gate, they are all equal. After they are in, it is up to the individual foreman to put them on the job.

MR. BERRY: We find that skilled or semi-skilled men are hard to get, so, for many years, we have attempted to and have trained our own people the way we want them to be trained. We rarely, if ever, hire a trained man.

In a new organization we are starting, we will have 2000 in a few months. Three weeks ago we had two men and today we have 180. We have found that we are able to take boys with a high school education, give them 4 weeks of concentrated training in welding and have over half of them able to pass a government certification for welding. It costs money to train them, of course, but, in the long run, we have found it much more satisfactory.

MEMBER: I would like to ask Mr. Berry what factors he considers when setting the merit rating on an individual operator.

MR. BERRY: Merit rating can never be an exact science. It is simply an individual or a group of individual appraisals of a man equated against qualities we hope our employees have. If we were selecting a

[1] Link Belt Co., Chicago, Ill.

man, we would put at the top of the list his desire to progress as an individual. A man with no desire to progress will have a very low merit rating. The most important thing we look for in placing a man is his interest in the job and in his fellow workers. We check from time to time, and the man who is effervescent, enthusiastic and gets along with his fellow workers is the man who rates highest. We do not mean a man who will not talk back, because if a man does not like something, we want him to tell us about it.

MEMBER: I would like to know Mr. Berry's opinion on placing a maximum on earnings for any particular piece-work job?

CO-CHAIRMAN WESTOVER: Do you mean a high limit above which you will not pay on a piece-work job?

MEMBER: Yes. Take for example an inspecting job where there is the possibility of the person on the job shoveling the objects into his container instead of inspecting them. Would you put a maximum on the job so that he will spend the time he should in doing it?

MR. BERRY: Are you speaking of an incentive job?

MEMBER: Yes.

MR. BERRY: In our opinion, the minute a ceiling is put on the earnings on an incentive job, the incentive system is not worth anything.

If a man does something dishonest and makes a lot of money, it is the fault of management. A piece rate or a wage incentive system should never be set unless it has been balanced and checked on each job. In our case, that is the job of the time study man. In other words, he goes over all the work tickets and all the earnings of all the men working on piece work each day. We keep an average earning of every productive worker in the plant on a wage incentive system. If a man cheats, he may not be caught today, but he will be tomorrow.

W. E. GEORGE[2]: Is it possible to compute the percentage of improvement in a job? Who keeps a record so that there is a new rate every time an improvement is made?

MR. BERRY: The Time Study Methods Department. We go back to our work standards and our records indicate how that job was done in every detail.

MR. GEORGE: In other words, every change, no matter how small, calls for a restudy of the rate. Do you put it up to supervision or up to the time study head to find that change?

MR. BERRY: Both.

MEMBER: What would be the method in making a reduction in rate or an adjustment in rate, if the supervisor does not tell about his change in method but it is accidentally discovered?

MR. BERRY: I cannot answer that because if the supervisor did that, he would no longer be a supervisor.

CHAIRMAN WARTGOW: Our foreman made changes in the jobs without telling anyone until some man who was supposed to make $1 an hour was making about $2.50 an hour. Then some one questioned the rate. To get away from that, we appointed a planning committee, and we are now

[2] Campbell Wyant & Cannon Foundry Co., Muskegon, Mich.

writing up in detail every move or every operation of the jobs in the shop. We draw up a print of the cope and the drag and the molding department, showing where the chilled dies are put, what size and how much, where the heads are, what size, etc., and there is not any one in the shop who can make a change until it comes through the planning committee.

J. H. HOCHMAN[3]: A company with which I was formerly connected had three major progressive assembly lines, with about 200 men on each line assembling quite a large commodity. We had a very good method and cost improvement department which followed all suggestions through. When the suggestions were put into effect on the major assembly line, if it was an improvement, we never could make the per cent change because the lines were manned to do a certain amount of work. The only way to change that was to re-evaluate the entire line from beginning to end, probably a 2 or 3 months' job. Every time we tried to make the changes, the cost reductions fell flat. If it was material savings, we got that, but no labor savings.

CO-CHAIRMAN WESTOVER: Mr. Wartgow mentioned that his company has set up detailed specifications of all jobs on which they are paying piece rates. Any who are just getting into this work or have a new union contract coming up will do well to make some provision that if a job is changed and the change is not caught at the time for readjustment of rate, the rate can be readjusted when the change is discovered, as soon as the order the particular operator is working on is out. It might be possible to write in the provision that the rate can be changed to the correct amount for what is being done at the time the change is discovered. However, from the psychological standpoint, it would be better to let the operator keep right on with the present order at the former rate.

R. G. WIELAND[4]: I believe both Mr. Berry and Mr. Wartgow said they were paying piece-work money on the basis of time studies and job evaluation. Do they also show the time study standards and unit hours for the men?

MR. BERRY: It is necessary to have a unit hour to interpret it into a dollar-and-cents value. In the event that a man complains about a rate, that man, the foreman and the time study man go over a complete and detailed analysis of it. When a time study is taken, the man who takes it or who sets it up from synthetic time must have it approved by the immediate department supervisors. He must have it further approved by the superintendent of that shop, whether it is a foundry or a machine shop, and he must have the okay and approval of the general superintendent.

You will say that is a long rigmarole to go through, but it is not because all of those men have had experience in the time study department. We cannot forget that we are dealing with a most vital thing in industry, namely, the setting up of wage payments. That is the reason the group of four people must approve a given time study before the rate is arrived at. We never put the unit time on the time card, but we have a

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[3] The Permold Co., Medina, O.
[4] Forest City Foundry Co., Cleveland, O.

standard showing the exact unit time for checking with the operator if he is in difficulty with his job.

MR. WIELAND: I believe a great mistake is made by not emphasizing time because it can be proved a lot better than some other things.

L. O. TAYLOR[5]: Do you penalize your operators, if they make an improvement in the job, or do you let them continue on at the old rate so that they get the benefit of the improvement they have made?

MR. BERRY: Suppose a man is doing a job and he is making $1.10 an hour on that job. The job is equitably paid for and equitably standardized as far as our ability would permit it to be standardized. The man is an ingenious chap and he finds a better and quicker way of doing it. We go out and make a new time study, and we set a fair and equitable rate. We will lean over backward a little bit and instead of making it $1.10 an hour, we will make it $1.20 an hour so he gets the ten-cent differential. This is not a written law but just a question of fair play. If he is good enough to think of a better way, we think he is deserving of an increase.

We have had a lot of experience with the so-called suggestion box. Our own opinion is that we do not like it because we have found no one in our organization able to properly interpret the value of a suggestion.

MR. GEORGE: If you deliberately let a man make $1.20 on a $1.10 job, are you sticking strictly to your system of standards data?

MR. BERRY: Yes, we are. We have a standard set up on which he makes $1.10. He is smarter than we are. He sets up a new standard, and we in turn set up a new standard. Standards may come and standards may go, but standardization goes on forever.

MR. GEORGE: But let us say it is a case of planning two cuts on the lathe operation, and a good operator discovered he could do it with one cut. He cuts the job down. He is allowed to make $1.20, but tomorrow there are three more jobs just like that which will require the same amount of cut. Will those three jobs be put back to $1.10?

MR. BERRY: That is not a correct and proper hypothesis. A machine tool is purchased and tested for the speeds and feeds it will take on a given alloy of steel or common steel. All of the cutting speeds are properly equated. We never measure the actual cutting time.

MR. GEORGE: But you do have a borderline where you assume it might be two cuts or one cut.

MR. BERRY: There is no borderline.

MR. GEORGE: What if you said it was two and the worker did it in one?

MR. BERRY: I cannot conceive of that. If the standards are properly set and the machines properly equated, that would not happen. We do all of our figuring on machine work cutting times from slide rules, and the figures are accurate and definite.

MR. GEORGE: I have seen workers better the speed and feed set up.

MR. BERRY: I have seen hundreds of workers beat all kinds of setups. That is why I say and have said time and again that the first thing to do when setting up a wage incentive system is to set up operating

[5] Campbell Wyant & Cannon Foundry Co., Muskegon, Mich.

standards. Many companies make a mistake because they will not spend the money, the time or the effort to set up proper operating standards.

MR. GEORGE: Did you improve your standards when carbide steels came in?

MR. BERRY: We started using carbide steels 3 or 4 years ago. No one could get a carbide tool from the tool room until it had been approved by the superintendent of the machine shop. We have reduced our rates on carbide tooling over 60 per cent. We had jobs that took 25 hours which were intermittent cutting on steel castings. We used to run 35 ft. per min. on intermittent cutting, and we now are running 210 ft. per min., so we have made a complete and revised new set of standards on carbide tools.

We expected trouble because there were a lot of rates that men had been working on for 10, 12 or 15 years, but we were disappointed because the reaction was entirely different. It is operating psychology, pure and simple. We did not just hand the tools to the man and tell him to run the feed at a set speed and let it go at that. We showed him the steel, told him all about it and had the superintendent and the time study man looking at it. We got him enthused because he was in the experimental stage of an era of new things. He did not complain about the rate. He made the same money or perhaps a little more than he had before. As a matter of fact, we figured he would make 10 per cent more because there were more hazards to the job at 210 ft. per min. than at 35 pt. per min.

MEMBER: Do you find it generally advisable to put inspection jobs on a straight piece-work rate?

MR. BERRY: We have yet to do our first inspection job on a wage incentive system.

MR. TAYLOR: We had a great deal of trouble with gas tanks. We had tank inspectors on piece work and some leaky tanks got through so we got the idea of paying a high piece-work price on any leaks, and we had a provision that if a tank was found leaking in the field, the inspector paid the loss, the return freight and the repair cost. Even with that provision the man made a good bonus on the piece-work plan and it stopped our leaks entirely.

We find it advantageous at our company to pay the inspectors for bad work rather than good work. On that basis, inspection can be put on piece-work rates just the same as any other work.

MR. LUBENKOV: How could inspection be set on anything that requires blueprint reading? For example, where intricate castings are concerned, the inspector might handle 10,000 different pieces in a week's time which would require a lot of blueprint reading.

MR. TAYLOR: On that kind of a job there would be a man who was more capable than just a rough casting inspector. If he was paid for finding faults, I believe it would work out successfully.

MR. LUBENKOV: Would you have a piece-work rate on it?

MR. TAYLOR: On the bad part he finds rather than on the good part.

MEMBER: Do you have any group piece rates?

MR. BERRY: No.

MEMBER: Where there are a number of closely associated operations and there is not room for each man to work individually to advantage, a group piece rate is placed on it. Suppose an improvement is made that will not actually increase the output of the line but will save half the time of a man if that time can be utilized in some way. Then, six months later, a way is found to take advantage of the other half of his time, and he can be taken off of the first job. What would be an equitable way to handle that?

MR. BERRY: I am sorry that I cannot answer that. You have proved to me very definitely why we have never put group piece-work in. The other men have been quite insistent that we put in group piece-work, particularly on major assembly jobs. I have always fought it because I could find no equitable way of taking care of it. That is particularly true in our shop, because we are primarily and basically an engineering plant which makes things rather than manufactures them. We do have a semi-standard item in a crane or shovel where four or six men may be working on it at a time. Our limit on group piece-work there is two men, the mechanic and his helper, and the job is broken down into various divisions of work. We set a piece-work price for doing one part and other piece-work price for doing another part.

MR. HOCKMAN: I would like to hear an expression on a really equitable way of setting up bonus plans for the supervisors in the core room and sand factory, one that is not just based upon weights and some fictitious values that will ultimately represent efficiency and is not equitable.

MEMBER: We have a foreman's bonus for the core room, molding department and cleaning department, based on a combination of the foundry scrap and of the return scrap. We figure out the saving that we would get on one per cent reduction in total scrap by the total financial operation over a period. Then, we figure the saving and give our foremen 50 per cent.

MR. GEORGE: Bonuses can be set in the foundry by many methods. The method I have seen work well in several companies is one relating the budgeted cost to the sales dollar. Budgets of so much per ton can be set, depending on the kind of work, etc., based on a study of last year's work or the last five years' work, separating the five years so there will be five pictures to study. In terms of the sales dollar, a fair budget can be decided for foundry work, for core workers, for cleaning work, for maintenance, and for metal cost. The costs can be related to the sales dollar if the sales department is in any way consistent. Having done that, management can say to the foreman, "Here is an expected or a fair cost for molding, $20 a ton for the kind of work we are running today, $18 for core work of the type we are doing today, and tomorrow, if it is more difficult work, you can expect a higher allowance." Using a direct ratio of yesterday's sales price to tomorrow's sales price, management can say, "The sales price has gone from $140 a ton to $180 a ton. Tomorrow we are going to allow you 18/14 of the amount allowed you yesterday." It works as fairly as any foundry method for budgeting.

MR. TAYLOR: We have had a little experience with the incentive bonus for foremen. The foreman wants money equal to, or a little more than the men who work under him. We hit upon the plan of paying the foremen just a little, probably 5 per cent, more than the highest piece-worker in the department. It worked well until the foremen began to push the men. The foremen have to be watched when the rate is set up, but it is a very satisfactory system when the foremen are loyal both to the men and to the company.

MEMBER: We have been budgeting our materials in the different departments for probably 10 or 12 years. We tried the foremen's bonus based on that. We also tried the foremen's bonus based on the earnings of the men in the shop. We were not very successful. We found the best way to do it was to base it on something which the foremen knew about from day to day and foundry scrap is something that they know about all the time. Any foundryman knows that a reduction in foundry scrap means a corresponding reduction in foundry costs.

MR. GEORGE: I believe twice as much time as is necessary can be spent on work, getting much higher costs than necessary, and perhaps have no scrap at all.

MR. HOCHMAN: We have hit upon a plan recently which we think is applicable to the foremen's and supervisors' bonus, namely, taking the book value of all the good castings produced at the first inspection point, and comparing that to the actual cost of the department, including all of the melters, molders, etc. Anything that is done to decrease the indirect labor would increase the percentage of the direct cost compared to the total cost. I do not know whether it could be called efficiency, but it would change the efficiency and it would provide a theoretical value to work toward.

MR. GEORGE: Fifteen years ago, I was with a consulting firm which then used supervision bonuses based on indirect ratios of labor and material cost to direct labor cost.

CO-CHAIRMAN WESTOVER: We used that system, but ours is now saving on units, the indirect cost against the unit as well as the direct cost against the unit.

MR. GEORGE: In other words, the overhead in the department should be, we will say, 75 or 125 per cent of labor. Are you making some type of ratio as a good figure for the foremen to aim at?

CO-CHAIRMAN WESTOVER: Our supervisors' bonus is based entirely upon the operating efficiency of the men in the department.

MR. GEORGE: How do you measure the efficiency of your indirect labor? Is it on term of ratio?

CO-CHAIRMAN WESTOVER: No. We have most of it on the basis of direct piece work on either a group bonus or a direct-man bonus.

A. W. PEIRCE[6]: Mr. Berry, in your time study department do you endeavor to teach a time study man to be able to go into the foundry, the machine shop or the fabricating shop to take the study, or do you say to two certain men, "It is your job to watch the foundry," and to

[6] Clark Equipment Co., Buchanan, Mich.

two other men, "It is your job to watch the machine shop"?

MR. BERRY: That goes through two stages. First, specifically, we take a foundryman who has worked in a foundry, and he eventually becomes a foundry time study man. Perhaps, after a few years, we transfer him to the machine shop and build him up if he is good enough and has enough aptitude to handle any of the three shops competently. We strive for that because it gives us flexibility of organization. We like to have one man capable of doing two, three, four, five or six jobs. We have found it very beneficial. We have perhaps four men in our plant who can make a job analysis in any of the shops, and it is rarely that even one can be found who can do that.

CHAIRMAN WARTGOW: Today, when men are needed in a hurry and it is not possible to train them in all the departments of a plant, it is better to break them in on one specific job. That applies not only to time study men but to machinists and skilled men alike.

Lumber for the Patternmaker and Foundryman—

Its Grades, Characteristics and the Effect of External Factors

By E. T. Kindt*, Cleveland, O.

Abstract

The author first presents a discussion of the structure of wood for pattern and foundry uses, next taking up a comparison of white and sugar pine and mahogany characteristics. He then describes factors in seasoning and kiln-drying. A very important section is presented on the basis of grading and an outline of grades and common causes of complaints. Other items covered are measuring, shrinkage and contraction, and effects of shop room atmospheric conditions.

1. This paper is presented with the thought of presenting ideas and information gained through years we have spent in contact with patternmakers and foundrymen. When we were first approached to present a paper at this meeting our first question was, naturally, what to present. After due consideration it seemed to us that the one thing that we had been questioned about most by the patternmakers and foundrymen throughout the country was lumber. This subject is universal and inexhaustible. Lumber is among the most important and least understood elements in our industry.

2. Lumber problems are manifold. We, therefore, respectfully submit to you this paper on pattern and flask lumber, the grades, characteristics and the effect of external factors, which we sincerely hope will contribute something to our important industry.

Structure

3. First is the question—"what is wood?" The chemical com-

* President, Kindt-Collins Co.

Note: This paper was presented at a patternmaking session of the 46th Anunal A.F.A. Convention, Cleveland, O., April 21, 1942.

position of wood is about 60 per cent cellulose, 28 per cent lignin, with minor quantities of other materials. Cellulose is colorless and forms the framework of the cell wall. The cells are similar to straw in minute form. Lignin is the cementing material that binds the cellulose together and is also mixed with cellulose in the cell wall proper. Color, odor and natural resistance to decay are credited to the approximate 2 per cent of the materials other than cellulose or lignin.

4. Fig. 1 is a cross-section of a tree trunk showing the well defined features and successions from the outside to the center. First is the bark, which may be divided into the outer corky dead portion, which varies greatly in thickness, and the thin inner living portion. Next comes the real wood which is clearly differentiated into sap woods and heart woods. Between the bark and the sap wood is a thin layer, invisible except under a microscope, called the cambium, in which all growth of a tree in thickness of bark and wood take place.

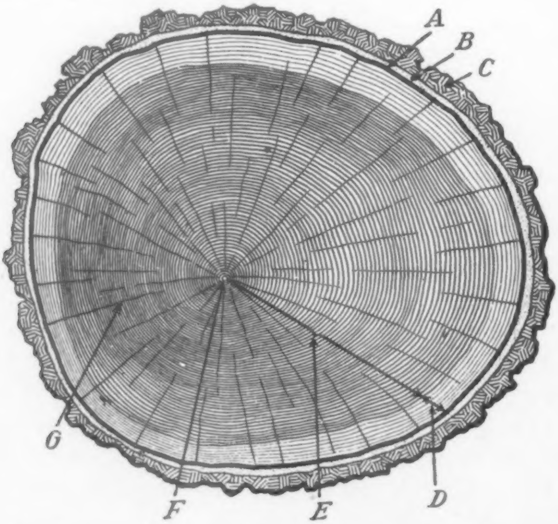

FIG. 1—THE TREE TRUNK. (A) CAMBIUM LAYER (MICROSCOPIC) IS INSIDE OF INNER BARK AND FORMS WOOD AND BARK CELLS. (B) INNER BARK IS MOIST AND SOFT. CARRIES PREPARED FOOD FROM LEAVES TO ALL GROWING PARTS OF TREE. (C) OUTER BARK OR CORKY LAYER IS COMPOSED OF DRY DEAD TISSUE. GIVES GENERAL PROTECTION AGAINST EXTERNAL INJURIES. (D) SAPWOOD IS THE LIGHT-COLORED WOOD BENEATH THE BARK. CARRIES SAP FROM ROOTS TO LEAVES. (E) HEARTWOOD (INACTIVE) IS FORMED BY A GRADUAL CHANGE IN THE SAPWOOD. GIVES THE TREE STRENGTH. (F) PITH IS THE SOFT TISSUE ABOUT WHICH THE FIRST WOOD GROWTH TAKES PLACE IN THE NEWLY FORMED TWIGS. (G) WOOD RAYS CONNECT THE VARIOUS LAYERS FROM PITH TO BARK FOR STORAGE AND TRANSFERENCE OF FOOD.

5. No growth in either diameter or length takes place in wood already formed (namely, center of tree). New growth is the addition of new layers, not the development of old ones. Branches of young trees originate at the pith or heart. As a tree grows the lower branches die and drop off. The dead stubs become covered with new wood and form knots. These knots vary in character and size according to the growth and inherent species characteristics.

6. The sap wood, or rings, surrounding a mature white pine tree is anywhere from 1 to 2-in. in thickness. The first limb on a matured pine tree may be from 40 to 70 ft. from the ground.

7. We give these few meager facts concerning the growth of a tree in order that one may better appreciate the fact that trees grow. They are a product of nature, and every tree has different characteristics, the same as human beings. Wood is, perhaps, the most misunderstood of the major materials that are used in pattern shops, and we are going to attempt to explain in a very brief manner a few things that every patternmaker and foundryman should know.

PINE

8. There are three species of pine, namely, northern white pine (*Pinus Strobus*), Idaho white pine (*Pinus Monticola*) and sugar pine (*Pinus Lambertiana*). All of these are soft woods and frequently called conifers, because virtually all three species bear cones and their leaves are needle-like. These three species are today being universally used for building patterns and flasks.

Northern White Pine

9. Northern white pine, originally known just as white pine, is found principally in the lake states and northeastern states and the Appalachian region. The wood is moderately light in weight, approximately 2100 lb. per M ft., moderately low in strength, and usually straight-grained. The soft, uniform texture of the virgin growth has won for it extensive use in building fine patterns. It changes dimensions little with changes in moisture content and is easily worked. The species makes a most desirable wood for patterns and flasks. Virgin growth is becoming rather scarce.

Sugar Pine

10. Sugar pine is a native of California and southern Oregon.

It is similar in appearance and properties to northern white pine, but can usually be distinguished by its most conspicuous resin ducts. It is somewhat softer than northern white pine, and will not carve as smoothly with hand tools, especially on end grain, as the northern pine. The finest quality of sugar pine is produced in the high altitudes of California.

Idaho Pine

11. Idaho pine is grown principally in northern Idaho, eastern Washington and western Montana. This species of pine resembles the northern white pine very closely. It is a trifle harder, a little more difficult to work, and is somewhat heavier, approximately 2300 lb. per M ft. It will swell and shrink a little more with changes in moisture content than northern white pine.

HARDWOOD LUMBER FOR PATTERNS

12. With reference to hardwood lumber for patternmakers, there is no question that mahogany holds the upper-hand today. There are three distinct species, namely, the Central American, Mexican, and Peruvian. The Central American and Mexican mahogany are almost identical in texture, weight and hardness. Peruvian mahogany is somewhat closer-grained, harder, and weighs more than the other two mentioned, 3800 lb. per M ft. All of the three species respond about the same so far as shrinking and swelling go in various humidities.

SEASONING LUMBER

13. Next let us consider seasoning of lumber. We are a firm believer in the water curing of logs. When the trees are felled, they are cut into lengths and then the logs are dropped into water where they remain for anywhere from one to two years. This process of letting the logs lay in the water for long periods will extract resinous material and also tends to cure the wood while still in the logs. Lumber cut from water-cured logs will positively be more mellow and has a tendency to relieve strains, and will dry a lot faster after once cut into lumber.

14. In our early experience, we can remember very distinctly that a number of the large northern white pine mills took pride in saying that all their logs were water-cured, and we have seen several years' cut of logs that were waiting to be cut up into lumber.

Today, this water-curing still exists, but the logs are not left in the water nearly as long.

15. After lumber is cut it is taken out into the yard and put into piles with strips in between each layer, or tier. The strips are evenly placed approximately four feet apart and care is taken so that each strip is exactly on top of the one that is under it, in order that the board will have the perfect support.

16. Most of the high grade mills protect their thick lumber, say 3-in. and 4-in., by boxing around it so as to retard the flow of air. This prevents checking. If this were not done it would be quite possible that the outside of thick lumber would dry too fast over the wet core. It requires about one year to every inch in thickness, to bring lumber down to the moisture content of the average humidity surrounding it.

17. The average moisture content of a thoroughly seasoned piece of white pine is anywhere from 10 to 14 per cent, depending upon the locality in which the seasoning takes place.

Length of Seasoning Important

18. For patternmakers to use air-dried lumber with any degree of satisfaction, it would be necessary to take lumber into the shop and again pile it on strippers and leave it to acclimate anywhere from 6 months to 2 years, the length of time depending upon the thickness of the lumber. Care would also have to be taken that any lumber so piled in the pattern shop would be properly ventilated. This method of acclimation would be perhaps the most ideal under the average shop conditions.

19. Some 20 years ago, we happened to be in a very fine pattern shop. The foreman of this shop, to whom we talked, had been in the employ of this company for some 35 years. He told us that his policy always had been never to use any lumber that had not been in his shop for three years, and he was very proud to show us several stacks of lumber 4-in. and 6-in. thick that had been there for 22 years. We mention this merely as it is such an unusual case. The average patternmaker does not give enough attention to the acclimation of lumber in his shop.

Kiln-Drying

20. Most of the pattern lumber that is used today has been kiln-dried. Today with the modern kilns it is possible to extract the moisture from lumber down to 6 or 7 per cent moisture content in a

fairly satisfactory manner. When lumber is put through the kiln it shrinks in measurement from 3 to 5 per cent, depending upon the moisture content of the lumber when it enters the kiln. Lumber will also degrade 3 per cent or more as kiln-drying brings out certain imperfections that cannot be seen in the air-dried lumber.

21. While preparing lumber in the modern kiln gives the workman dry lumber, however, we do not believe that this is yet the final answer to the many discrepancies to accurate pattern work. We will come back to this subject a little later.

Grades

22. We would like to say a few words about various grades of pattern and flask lumber from a practical angle. A matured tree, one cut into lumber, yields boards of various grades. These grades divide the product of the tree into numerous segregations, each having a relatively narrow range in quality which enables the respective user to purchase the grade that suits his purpose, providing, of course, he has a clear understanding of grades.

Basis of Grades

23. A grade of a board is based on the number, character and location of such defects as knots, mineral streaks, pitch pockets, rot, sometimes called doze checks, shake and stain. Most of these defects are a natural part of the tree. The various imperfections mentioned do not prevent the use of such lumber from giving entire satisfaction when used for the proper purpose.

24. While time does not permit us to go too deeply into the matter of grading lumber, however, we wish to give sufficient information for those who are interested so that they can get grading rules for both the soft woods and hardwoods.

Sugar Pine and Idaho Pine

25. Sugar pine and Idaho pine come directly under the standard grading rules as published by the WESTERN PINE ASSOCIATION which is the administrative agency of lumber code authority in the western pine division. Their address is Portland, Oregon. In their book of rules they say:

> "The purpose of grades is to maintain a standard of measure of value between mills manufacturing the same or similar woods, by harmonizing the natural differences existing between the different

stocks of lumber regardless of the character of the logs from which they are produced, regardless of the mill from which it comes. Uniform grades also provide both buyers and sellers of lumber with a measure by which each can determine whether he is buying or selling full value."

26. We refer those using northern white pine to the NORTHERN PINE MANUFACTURERS ASSOCIATION, Minneapolis, Minn., who also issue a book on grading rules. These rules differ slightly from the WESTERN PINE ASSOCIATION rules.

Mahogany

27. All mahogany comes under the NATURAL HARDWOOD LUMBER ASSOCIATION rules, whose address is 2408 Buckingham Bldg., Chicago, Illinois. Hardwood grading rules differ greatly from the pine rules. In pine rules, we maintain that there are nine grades suitable for pattern work, and two grades that are suitable for foundry flask and slip jacket work.

Recommendations

28. In both sugar pine and Idaho white pine, which come under the WESTERN PINE ASSOCIATION grading rules, our recommendation is that grades from F. A. S. CLEAR all the way down to the No. 2 COMMON AND BETTER, have a distinct place in the pattern shop, as do the northern pine grades from the B. & BETTER down to the No. 2 COMMON.

29. For foundry work, in the northern white pine grades, we recommend the No. 2 and No. 3 COMMON for flasks, depending entirely upon the size and service required from the particular flask and slip jackets to be built.

30. In the mahogany field there are five grades that cover the entire field.

31. It is urged that the foundryman and patternmaker keep in mind that the human element enters into the grading of lumber. Each grade has its respective low and high line boards. Certain tolerances must be accepted.

32. Our observation, over a period of years, has been that during times of depression and lower labor costs, cheaper and lower grades of lumber are demanded for pattern and foundry work. The demand for higher grades increases with labor costs and more prosperous times.

USE OF VARIOUS GRADES VS. COST

33. The writer recalls an experience he had calling on two competitors located in the same town. Both were building the same large class of patterns. One was using a No. 1 COMMON grade and the other was using a C SELECT & BETTER grade. We maintain that in this case the party using the No. 1 COMMON was producing patterns equally as good as the one using the C SELECT. At the same time he was saving his firm approximately $40.00 per M ft. Here again is where the human element entered into the picture, and it was one man's opinion against the other's.

COMPLAINTS

34. Below are enumerated five of the most common reasons for complaints in respective order:

(1) Not the grade ordered, or expected.
(2) Lumber not sufficiently dry.
(3) Lumber too prone to twisting, warping or splitting.
(4) Too much narrow stock.
(5) Lumber too cross-grained or too hard textured, or too much pitch.

35. There is no question in our mind that each user has had complaints as enumerated, perhaps many times. No grading rules cover complaints Nos. 2, 3 and 5. Here we might mention that too often pattern and flask lumber is bought strictly on price. There are a number of very fine concerns who are specializing in pattern and flask lumber, and they can give the user, without question, the most satisfactory material dollar for dollar over any period of time. It only makes common sense.

RECOMMENDS MARKING

36. I firmly believe that the AMERICAN FOUNDRYMEN'S ASSOCIATION could profitably appoint a committee to recommend and standardize grades and species of pattern and foundry lumber. Such a move would be a step in the right direction and save thousands of dollars for the affiliated members.

37. The purchaser of off-grade lumber has the recourse of applying to any one of the three lumber associations as mentioned before for a re-inspection of grade. The expense of re-grading is borne by the buyer if the grade is found to be correct. If more

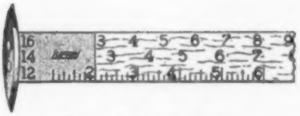

FIG. 2—BOARD RULE.

than 4 per cent in hardwood, and more than 5 per cent in pine, is off-grade, the shipment can be returned and all expense is borne by the seller.

MEASURING

38. To measure lumber properly one must do so with a standard lumber rule so graduated that it calculates the number of surface board feet in any length piece. Surface measure means the contents of a board on the surface. Boards are measured in thickness by quarters. One-in. is called 4/4, 1¼-in. is called 5/4 and 2-in., 8/4, etc. When the lumber shows 16 ft. surface and the lumber is 1-in. thick, or 4/4, there would be 16 ft. of lumber in the board. If the lumber is 2-in. thick, or 8/4, one doubles the surface measurement of 16 ft. or 32 ft. contained in the 2-in. board. Remember less than 1-in. thick is always measured as 1-in. Quoting from one of the grading rule books regarding measurements:

> "A material measured with a board rule on actual widths, pieces measured to the even half foot shall be alternately counted as of the next higher and lower foot count. Fractions below the half foot shall be dropped and fractions above counted as of the next higher foot.
>
> "Because of the variable human element in the application and use of a board rule, a difference of not to exceed 1½ per cent shall be considered a reasonable variation between tallies."

SHRINKAGE AND EXPANSION

39. The subject of shrinkage and expansion is rather technical, but of vital interest. The word "bone-dry lumber" is often used yet really means nothing to a patternmaker. Tremendous amounts of money are wasted annually on correcting wood patterns. Besides, a great deal of metal is wasted for the reason of patterns swelling out of shape and losing the costly accuracies built into them. Wood naturally shrinks and expands according to atmospheric conditions which surround it.

EFFECTS OF MOISTURE IN AIR

40. Air always contains some moisture in the form of invisible vapor and this quantity of moisture is variable from day to day and from one locality to another. When a pattern is exposed to the atmosphere in which the quantity of moisture is variable, it quickly changes in moisture content* and shrinks or swells or twists accordingly.

41. No matter how thoroughly or carefully the lumber may have been dried or seasoned it daily changes its moisture content taking on or giving off moisture to adjust itself to changing atmospheric conditions. Contrary to the general opinion, when wood is air-dried, it finally reaches a moisture content below which it does not go no matter how long it may be seasoned, unless there is a decided change in the atmospheric condition.

LONG TIME EFFECT

42. The FOREST PRODUCTS LABORATORY of the United States Forest Service, Madison, Wis., is responsible for the statement that a quantity of black walnut, after being air seasoned in an unheated building, but protected from the weather for 60 years, had a moisture content of 11.6 per cent. Over half a century of air seasoning failed to reduce the moisture content of this particular lot of lum-

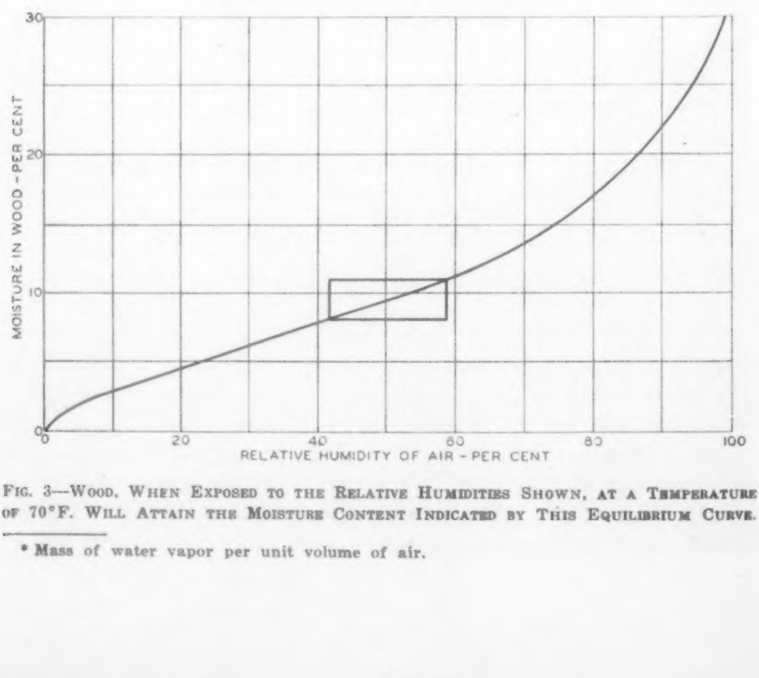

FIG. 3—WOOD, WHEN EXPOSED TO THE RELATIVE HUMIDITIES SHOWN, AT A TEMPERATURE OF 70°F. WILL ATTAIN THE MOISTURE CONTENT INDICATED BY THIS EQUILIBRIUM CURVE.

* Mass of water vapor per unit volume of air.

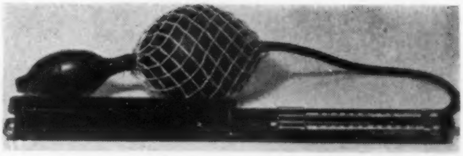

FIG. 4—PSYCHROMETER—FOR TESTING RELATIVE HUMIDITY.

ber so that one would be able to build patterns from it with any degree of accuracy during the winter months. We believe the reason for that is that in practically all the pattern shops we have ever seen, the relative humidity is too low, especially so when the outside temperatures are below freezing. We have, personally, tested many shops for relative humidity, and we can frankly say that we have never found two shops which were alike in this respect in the same town on the same day.

SHOP CONDITIONS

43. Too often, pattern lumber has been condemned as being too wet when actually the lumber has not been at fault, but the outside influence surrounding it. In all of our experience, we have failed to ever hear a patternmaker say "it's the condition of our shop and not the lumber that is giving us the trouble".

44. During winter months, when windows and doors are closed, and dry, artificial heat is used, pattern shops become extremely dry, often dangerously so. When properly seasoned lumber is brought in it actually seems wet, and will shrink.

One Example

45. Only a short time ago following a very cold snap, we had an opportunity to make a thorough check on a large jobbing pattern shop building aircraft engine patterns which was having trouble with lumber and patterns checking and shrinking. We first checked the rough lumber in the lumber rack with an electric moisture content tester and found it to have from 8 to 9 per cent moisture content. We also checked some pine pieces approximately 12 in. square by 5 ft. long which had been glued and which showed considerable check.

46. These pieces registered 7 per cent moisture content on the outside. We also checked several bench tops and found them to be less than 6 per cent. The relative humidity was then checked with a wet and dry bulb checker and found to be 34 per cent which

would put lumber in equilibrium with less than 7 per cent moisture content.

47. We found the relative humidity* in the location of the lumber storage rack to be 42 per cent. The trouble with this particular shop, as we figured it, was that the lumber was being brought into the pattern shop from the lumber rack and was drying out too fast on the outside.

SHRINKAGE AND CHECKING

48. When lumber dries it will shrink. Consequently, checking results. Now what would one expect to happen to wood patterns and coreboxes built accurately and dried out to a 6 per cent moisture content when taken to a foundry and surrounded by wet

FIG. 5—WOOD TESTER—ELECTRIC MOISTURE TESTING APPARATUS.

* The ratio of the water present in the atmosphere to the quantity which would saturate at the temperature of the air at the time.

FIG. 6—MAHOGANY LOG IN THE DEPTHS OF A TROPICAL JUNGLE.

sand. We do not have to tell you, you know the answer. If the work is very complicated it will require many man hours to again make cores fit and centerlines check. Discrepancies of this sort can be directly attributed to faulty atmospheric conditions in your shop and storage vault.

49. We often hear pattermakers talking about splitting 1/64ths of an inch on wood patterns and using veneers and occasionally

FIG. 7—MAHOGANY LOGS IN WATER.

micrometers. A 12-in. flat grained pine board will shrink 1/16th of an inch when the moisture content is reduced from 12 per cent to 7 per cent. Wood shrinks most in the direction of the annual growth ring tangentially, commonly called flat grain, and about one-half to two-thirds as much across these rings radially, called edge grain. Practically no shrinkage or expansion takes place longitudinally except when a board is excessively cross-grained and lengthwise shrinkage is a combination of crosswise and longitudinal change.

50. The percentage of moisture content recommended for either pine or mahogany is selected for the purpose of reducing changes in moisture content to a minimum, thereby minimizing dimensional change after the patterns and coreboxes are put into service or stored away.

MOISTURE CONTROLLED STORAGE

51. To you we wish to say that our experience has been that the average patternmaker has paid too little attention to moisture content of lumber and relative humidity in patternshops and storage vaults. A moisture meter for testing lumber and a wet and dry bulb instrument for testing humidity can be bought at a very nominal figure. By the proper use of them you will be greatly benefited and we predict that as time goes on, pattern shops and storage vaults will be humidified or moisture controlled.

DISCUSSION

Presiding: E. J. BRADY, Western Foundry Co., Chicago, Ill.

Co-Chairman: A. PYLE, JR., Pyle Pattern & Manufacturing Co., Muskegon, Mich.

CHAIRMAN BRADY: I think the suggestion that we look into the matter of moisture-measuring instruments will be very beneficial. In years gone by, we have condemned lumber entirely after checking patterns and finding shrinkage and haywire center lines. I think we should qualify that in the future by checking to see whether or not the room is properly humidified and, in that way, protect both the lumber and ourselves.

MEMBER: I happen to be a user of Idaho White Pine and have been using a moisture meter for the last three years which I find very helpful. However, I would like to bring out the fact that there are two types of moisture in pattern lumber. One of them is the original sap which

comes into lumber as it grows and which is supposed to be removed by the lumber manufacturer in the process known as dry kilning.

Today, unfortunately, lumber mills do not have time to properly cure lumber. They claim that we patternmakers should be satisfied to receive the lumber with a moisture content of 10 to 12 per cent. When we get the lumber in that state there is not enough of the original sap taken out of it. Not enough steam has soaked into the lumber to wash out the sap when it is dried. For that reason, when it goes into hot places or dry places and comes out into moisture again, its size changes too fast.

On the other hand, if we could in some way get our lumber manufacturers to cure our lumber down to approximately 8 per cent, it would break down the cells in that lumber, close them and get the moisture out. Once they are closed, the lumber could be subjected to atmospheric conditions. If subjected to damp weather, they, naturally, will pick up the moisture, but it is mostly surface moisture, and after that the change in the lumber would not be so great as otherwise.

MR. KINDT: I made a statement about checking up a pattern shop in Cleveland. I maintain that the patternmaker is really not scientific enough from the standpoint of relative humidity in his own pattern shop. He tries to build a marvelous, accurate, fine pattern and he disregards the fact that the humidity might be so low that the pattern, during the process of building, will shrink out to a point that, when it is taken back into the foundry where the humidity is considerably higher, it will change, and no curing in the world will ever eliminate that. So my recommendation would be to humidify the shop to a point where lumber will equalize itself around 10 per cent moisture content and then, when taken back out in the foundry, the change will not be nearly so great. Yet there will be some change even at that.

In the particular shop I mentioned, it was figured out that when the weather was zero, it would be necessary to evaporate 185 gallons of water every 24 hours to keep the shop properly humidified so that patterns would keep from shrinking and checking.

R. D. SPEIRS[1]: We have been a user of great quantities of mahogany for the last 20 years. Our specifications call for the delivery of mahogany with a moisture content of between 7 and 9 per cent. Today we have wood patterns that have been running since 1927, still giving us high production. We control our lumber by putting it in dry storage, bringing it up to the shop and letting it acclimate itself to the atmospheric conditions for a period of three months before going into patterns. Our foundry is a dry shop of concrete construction with concrete floors. In this way we have kept our pattern lumber about where it should be.

I agree with Mr. Kindt that a lot of our pattern lumber troubles are to be found in our own pattern shops and foundries, but I do believe that the lumber manufacturer should try to break down the moisture content and let us pick up the difference in the shop.

MEMBER: We manage to keep high enough humidity in our shop to prevent the lumber from drying while in the shop. It goes into the found-

[1] Wright Aero Corp., Paterson, N. J.

ry to be cast after which it goes up to the second or third story where it is much drier than in the shop. What will happen to the pattern then?

MR. KINDT: It will be the same in the storage vault as it would be in the dry pattern shop. It will shrink. Today there are several large concerns that have installed humidification systems in their storage vaults, and they have saved themselves thousands of dollars. Formerly they had a dry storage vault and two men doing nothing but repairing and changing patterns, making the center lines check and the core fit. This has been eliminated to a large degree because of the humidification. Wood will change in any climate and all the curing in the world will not affect that. A piece of lumber can be dried down to 5 per cent and varnished. If it is put in a higher humidity, in ten days it will have acclimated itself to the higher humidity.

CHAIRMAN BRADY: Will patterns pick up moisture after they are properly varnished or shellacked on all surfaces?

MR. KINDT: There is no known pattern coating today that is moisture-proof, contrary to the general opinion. Moisture is not the same as water. It is an invisible vapor that will penetrate almost everything except glass and metal.

A. K. LAUKEL[2]: A rather new process for the treatment of lumber to eliminate end checking is the use of urea, which also might be used for printing pattern lumber. The end of the lumber is treated after it is cut and that stops the checks, the urea setting the sugars and materials in the wood. It might be the solution to the problem of expansion and contraction in pattern lumber. Some of the work was done at the Forest Products Laboratory in Wisconsin.

MR. KINDT: One way of eliminating moisture would be by saturating the lumber with certain kinds of oils or water-resisting liquid so that water would not penetrate it, but that would be very impractical.

CHAIRMAN BRADY: Has any one had any experience with treating lumber to make it fireproof or as nearly so as possible? Are there any satisfactory standard methods of doing it?

MR. KINDT: There are several materials on the market today that are fire-resisting, but they are not fireproof.

MR. LAUKEL: If it is a case of water vapor absorption in a piece of lumber, say, about 2-in. thick, how can water vapor reach down into the center if it is just water hitting the surface? The checking action is due to osmosis. There is sugar in the cells and, due to the osmosis, there is a tendency to dilute the concentration in the cells. As soon as the water hits the surface of the board it starts osmosis and goes down through the center of the lumber. I cannot see how a change in humidity in the room from one day to another would change it just by having a change in moisture content. There must be some other reactions. If those materials can be set in the cells there will be a tendency to eliminate the expansion and contraction in that lumber. It is possible to get the moisture down in a 2-in. plank by osmosis. Water in a tree will climb overnight,

[2] Electro-Chemical Pattern & Mfg. Co., Detroit, Mich.

and sap will go up in a tree in from 2 to 15 minutes. I believe the situation is similar in the case of lumber.

MR. KINDT: The fact still remains that lumber and wood patterns change in size with changes in atmospheric conditions. Osmosis is the equilibriums of pressure between two solutions when one in a semi-permeable cell is immersed in the other. As stated previously, in order to overcome a large percentage of our present-day troubles with patterns and lumber changing dimensions, one must closely head up relative humidity with moisture contents of lumber. This can be done by controlling humidity in shop and storage vaults, acclimating lumber and building wood patterns in that humidity.

Seacoal and Fuel Oil in Molding Sand

By Elmer C. Zirzow*, Cleveland, Ohio

Abstract

While seacoal has been used in foundry sand for a long time, the use of fuel oil is relatively a new development. In this paper the author first discusses seacoal, giving the theories on its action in a mold upon the application of heat, points that should be taken into consideration in the selection of seacoal for use, the proper constituents of seacoal and methods of adding seacoal to both floor heaps and system sands. Of considerable importance are the factors determining the amount of seacoal to be added and a method for determining the amount of seacoal in foundry sands. The author also discusses the effect of this material on the properties of sand and the defects caused by the improper use of seacoal. The second section of his paper is devoted to the use of fuel oil in foundry sands. He points out that while this is a comparatively new development, the use of this material, along with seacoal, in foundry sands was known as long as 10 years ago. In addition to discussing the factors which led to the use of fuel oil in molding sand in the foundry of the company with which the author is associated, he explains methods of adding fuel oil, typical sand mixtures, their uses, and the effect of fuel oil on the properties of sand. Of particular interest are the savings effected by the use of fuel oil in conjunction with seacoal in iron foundry sands.

1. As far as is known seacoal originally derived its name from the fact that it was a coal which was shipped by sea or taken from mines which were located beneath the sea in Wales. At the present time, when we speak of seacoal, we refer to any ground coal dust.

2. Seacoal is ground in various types of mills and pulverizers to varying degrees of fineness. Some foundries find it profitable to

* Core Room Foreman, National Malleable and Steel Castings Co.

Note: This paper was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

grind their own product but the majority of users prefer to purchase it in the ground state.

3. Seacoal is placed in molding sand for two reasons:

(1) To prevent the sand grains from burning onto the metal.
(2) To improve the finish of the casting.

Theories on Seacoal Reaction

4. Several theories have been advanced as to the action of seacoal in preventing the sand from burning onto the casting but perhaps the most logical explanation, and the one that has the most merit, is that of a reducing agent. By the introduction of any carbonaceous material, the atmosphere on the inside of the mold is held free from oxygen.

5. This oxidizing material must be present to form the iron silicates that are found on the surface of burned-in castings. This theory is further substantiated by the fact that the amount of seacoal must be increased directly in proportion to the temperature at which the castings are removed from the sand.

6. In other words, if a casting is removed from the sand, after it has cooled completely, the amount of seacoal required for the mold will be less than in a mold from which the casting is shaken after it has just barely solidified. The latter condition is true of most castings made on continuous conveyors where the time cycle of the conveyor is not long enough to permit the casting to cool to a dull red or black heat. When castings are dumped from conveyors in this condition, the oxygen of the atmosphere has an opportunity to react with the sand grains and iron to form the iron silicates. This must be prevented by having sufficient carbonaceous material present so that the oxygen will react with this material rather than with the iron and sand.

7. The fact that it is impossible to ram molds to such a degree of hardness that the openings between the sand grains would be microscopic in size, is the reason why seacoal must be used to improve the finish. This is accomplished not only by the coking action of the coal, but also by the gas content which causes a cushion to be formed at the surface of the casting. This gas cushion, along with the coke, fills all the voids between the sand grains giving the desired smooth surface.

Effect of Heat Application

8. A mold can be compared to a retort for the distillation of

coal to form coke. The heat is applied by the molten metal entering the mold cavity. The first reaction that takes place in a green sand mold is a drying action. All the tempering moisture must be first driven from the mold at the casting surface. The temperature then rises until the combined moistures of the clay and seacoal are driven off. Finally, the distillation of the coal commences.

9. As the distillation of the coal proceeds, the seacoal becomes a fluid tarry mass filling up the voids created by the contraction of the clay and the expansion of the silica grains. These reactions occur almost simultaneously and can be noted by observing the pouring of any green sand mold to which seacoal has been added.

10. First the steam is noted issuing from the mold, then the blue flame caused from the ignition of the water-gas which is formed just as the distillation of the coal starts, and finally the smoke or distillation products. If the sand is examined carefully after the mold has been shaken out, minute particles of coke can be found.

SELECTION OF SEACOAL

11. Several factors must be taken into consideration in the selection of the proper seacoal:

(1) Weight of the casting.
(2) Surface area of casting.
(3) Cross-sectional area of casting.
(4) Grain fineness of sand.

Weight of Casting

12. The weight of the casting enters into the selection of the proper seacoal only because of its effect on ferrostatic pressure. The fixed carbon for heavy castings should be greater than for light castings; in other words, more coke and less volatile combustible matter (V.C.M.). The opposite is usually true of a light casting.

Surface and Cross-sectional Area

13. The surface area and the cross-sectional area of the casting must be taken into consideration because of the possibility of misruns or cold shuts. In a light, thin-walled casting with an excessive amount of V.C.M. present, the gas formed will chill the iron. On castings with a large surface area, the binding action of coke or fixed carbon is necessary to prevent buckles in the sand. On the

other hand, the chilling action of the V.C.M. will prevent the temperature of the sand from becoming excessive.

14. In other words, the seacoal function is one of compensation on one hand for the contraction of the clay, and on the other hand the expansion of the silica grain. This does not mean that seacoal will be a cure-all for defects of this type.

Sand Fineness

15. The grain fineness of the sand will help to determine the amounts of seacoal and its desirable fixed carbon. The coarser-grained sands usually require a seacoal with a high fixed carbon and a low V.C.M. The opposite is usually true of finer-grained sands. It also is usually considered advisable to use a fine ground seacoal with a fine-grained sand and coarse seacoal with a coarse-grained sand.

ANALYSIS OF SEACOAL

16. Seacoal should be analyzed for the following:

(1) Volatile combustible matter.
(2) Fixed carbon.
(3) Total carbon.
(4) Sulphur content.
(5) Ash content.
    (a) Ash fusion
(6) Fineness.

It is necessary to analyze for V.C.M. to determine the amount of gas which will be produced. The fixed carbon likewise will determine the probable amount of coke that will be produced by a unit volume of coal. The total carbon is used, in some cases, in determining the seacoal content of the sand. This determination is not absolutely necessary. An excessive amount of sulphur is not desirable in a seacoal.

17. The ash content should be as low as possible to lessen the contamination of the sand heap from that source. Ash fusion point should be held as high as possible because, if it is too low, the ash will fuse with the sand and metal. Fineness is important not only from the standpoint of proper distribution in the sand, but also for its effect upon the coking action of the coal. As explained previously, the desired fineness of the seacoal is usually dependent upon the fineness of the sand.

METHODS OF ADDING SEACOAL

18. Seacoal can be added to foundry sands in any one of four ways:

(1) Raw.
(2) With rebonding mixture.
(3) With facing sands.
(4) With burned sand at mill.

19. The simplest way is to add the seacoal raw or distribute it evenly on the heap and cut it in with an ordinary sand cutter.

Addition to System Sands

20. For continuous systems, which do not have any mills in conjunction with them, the seacoal is added directly to the sand tempering belt. This method is not the most desirable because of the impossibility of getting a thorough mix. There is also the chance of seacoal mixing with the clay and forming balls of seacoal and clay. The danger of segregation is always greater when seacoal is added in this manner. However, with the proper amount of control, it can be added in this way and very satisfactory results can be obtained.

21. In some cases, seacoal is added with the rebonding mixture, but here again there is always the danger of segregation. A rebonding mixture must, of necessity, be rich in clay and, even under the most careful milling conditions and unless the rebonding mixture is held on the dry side, the seacoal and clay will have a tendency to ball-up.

22. Wherever possible it is advantageous to run a facing sand rich in seacoal. In the preparation of the facing sand, mixing conditions are usually ideal. However, in continuous systems, the amount of facing sand used is so small that it is impossible to get enough seacoal into the systems by this method.

23. Usually on continuous systems, there is a quantity of burned sand or core sand coming off the casting cooling conveyors. This sand can be returned to the mill and mixed with a high percentage of seacoal. This method is by far the most satisfactory but, in many cases, it is not practical, either because of mill capacity or because there is not sufficient burned sand coming from the casting conveyor.

24. The systems which have the mills directly incorporated provide the best means of adding seacoal. In this case, small

amounts of seacoal and clay are added continuously and a thorough mixture is assured.

Factors Determining Amount of Seacoal Added

25. The amount of seacoal to be added is dependent upon:

(1) Amount of burned core sand.
(2) Condition of castings when dumped.
(3) Length of time castings are in contact with sand.
(4) Area of casting surface.
(5) Thickness of various cross-sections of castings.
(6) Metal pouring temperature.
(7) Permeability of sand.

Amount of Burned Core Sand

26. Burned core sand which becomes incorporated into the system or heap at the shake-out, increases the volume of the sand grains. Additional seacoal must be added to compensate for this material. There is, however, a slight amount of carbonaceous substance remaining on these grains from the oxidation of core oil.

Condition of Castings When Dumped

27. If a mold is dumped just after solidification of the metal, the percentage of seacoal in the sand must be greater than in a mold in which the casting is cooled to a black heat. This has been explained more fully previously. However, the distillation of the coal will proceed to a greater depth in the latter.

Casting Area and Cross-section

28. The greater the surface area of the casting the greater will be the amount of seacoal that will be converted to ash. Likewise, the greater the cross-sectional area of the casting, the greater will be the heat penetration of the sand.

Pouring Temperatures

29. Higher metal pouring temperatures necessitate greater additions of seacoal. Fifty degrees F. difference in pouring temperature will produce a marked effect on the appearance of the castings.

Permeability

30. Higher permeabilities in sands permit greater dissipation of heat through the sands with the resultant effect upon the seacoal.

DETERMINING SEACOAL IN FOUNDRY SAND

31. Various methods are used for determining the seacoal content of foundry sands. R. E. Aptekar gives a detailed and elaborate method. However, for ordinary control work, a total carbon determination is all that is necessary. This is assuming that all operating conditions are constant, and that there will not be a big difference in the volatile combustible matter in the sand.

32. Still another method used for controlling the amount of seacoal, is to keep a record of the pounds of seacoal used per ton of metal poured. Regardless of which method is used, the percentage of seacoal used is determined largely by the appearance of the castings' surfaces.

EFFECT OF SEACOAL ON SAND PROPERTIES

33. The following properties of foundry sand are affected by the addition of seacoal:

(1) Green strength.
(2) Permeability.
(3) Contraction and expansion.
(4) Deformation and resiliency.
(5) Moisture.

Green Strength

34. One investigator shows that an addition of 12 per cent seacoal to a sand, that has not been contaminated by ash, will double its green strength. However, when any ash is present, this does not hold true to such a marked degree. The reason for this increased green strength with the addition of seacoal is not easily explained. In all probability, a better distribution of the clay around the sand grain is obtained. The coating of clay is actually thinned out around the grains thereby approaching more nearly the maximum efficiency of the adhesive property of the clay bond.

Permeability

35. The slightest addition of a seacoal to a foundry sand will lower the permeability. The cause for this is self-explanatory. Seacoal, being a very fine material, helps to fill the voids between the sand grains. As the seacoal percentage in the sand is increased, the permeability is diminished.

Expansion and Contraction

36. Seacoal decreases both the contraction and expansion of molding sand. Dietert and Valtier[1] prove this quite conclusively. This was also pointed out earlier in this paper under the description of the action of seacoal during the pouring cycle.

Deformation and Resilience

37. Dietert[1] and Valtier also show that the deformation of a molding sand will be increased with the addition of seacoal up to 6.0 per cent. If the percentage is increased to over 6.0 per cent, the deformation will be reduced gradually as the percentage is increased. The resiliency is affected likewise, although it is decreased less rapidly after reaching the 6.0 per cent peak. The reason for this is that, although the deformation decreases after a 6.0 per cent addition, the green strength still increases. As a matter of fact, the resiliency curve becomes almost a straight line.

Moisture

38. Seacoal, being a very fine material, has a very large surface area. This increased surface area necessitates an increase in the moisture content of the molding sand to obtain a proper temper. Unfortunately, this increases the amount of steam produced in the pouring operation. This serves in a small degree to offset the efficiency of the seacoal.

PENALTIES FOR IMPROPER USE OF SEACOAL

39. Certain casting defects can be directly attributed to the improper use of seacoal:

(1) Rat tails.
(2) Cold shuts.
(3) Misruns.
(4) Dirt.
(5) Drops.
(6) Surface checks.

40. All these defects are caused by the addition of too much seacoal. Cold shuts usually occur in thin-walled castings. If the molding sand is too close and too much gas is produced, castings will misrun. These misruns usually appear on the sharp contours

1 Dietert, H. W., and Valtier, F., "*The Expansion and Contraction of Molding Sand at Elevated Temperatures*," TRANSACTIONS, American Foundrymen's Association, vol. 43, pp. 107-124 (1935).

of the castings, especially on the cope half. Surface checks are similar to cold shuts, but will occur on any wall section. Dirt and drops are caused by the contamination of the molding sand by the ash and by not observing the usual precautions in tempering sand. Improper mixing of the seacoal will produce rat tails. This defect is not common but can be noted occasionally.

FUEL OIL PLUS SEACOAL

41. Fuel oil can be used in conjunction with seacoal. The practice of using fuel oil in foundry sand is comparatively new and not a great deal is known about its effect. W. G. Reichert mentioned the use of fuel oil in foundry sand in an article published about 10 years ago.

42. The greatest objection to the use of fuel oil is the amount of smoke or fumes produced. Some foundries make a common practice of oiling metal patterns. Castings made from the molds, after a pattern has been heavily oiled, appeared to have a much cleaner surface.

43. After repeated observations of this condition, the oil was incorporated directly into the sand heap. This was tried first on a small sand heap. The results were most gratifying. Not only did the castings have a better finish, but the stickiness of the sand was reduced considerably. However, it was still necessary to oil the pattern occasionally.

44. After this trial on the single heap, fuel oil was added to one of the sand systems. The same results were noted. However, in the sand systems, it is much easier to control the physical properties of the sand. To begin with, no changes were made in the sand properties or in the percentage of seacoal.

45. Any ordinary fuel oil may be used for this purpose. An oil with a low percentage of sulphur and a Baumé gravity between 20° and 30° has given the most satisfactory results.

Methods of Adding Fuel Oil

46. Fuel oil may be added to the molding sand in the same manner as seacoal, namely:

(1) With facing.
(2) Attempering belt.
(3) With rebonding mixture.

47. A definite predetermined amount may be added with each

batch of facing sand. The quantity of oil added per batch is dependent upon the requirements of the facing in the foundry. Additions of oil will vary from one quart to 3 gallons per 800 lb. batch of sand. The oil is added at the same time as the tempering moisture.

Typical Mixtures

48. The following are some typical sand mixtures which can be used:

Mix No. 1
40 shovels system sand
8 quarts oil

Mix No. 2
35 shovels system sand
5 shovels bank sand (grain fineness No. 100)
200 cubic inches seacoal
5 quarts oil

Mix No. 3
40 shovels sand
2 shovels sharp sand (grain fineness No. 30)
100 cubic inches Southern bentonite
100 cubic inches Western bentonite
50 cubic inches cereal flour
200 cubic inches seacoal
1 quart oil

Mix No. 4
40 shovels system sand
100 cubic inches Western bentonite
150 cubic inches cereal flour
600 cubic inches seacoal
12 quarts oil

49. Mixtures Nos. 1, 3 and 4 were used for specific types of castings. Mixture No. 2 is an all-purpose facing and is the most widely used.

50. As far as can be ascertained, the most efficient method of adding the oil to the systems is to make a constant addition at the pug mill immediately after the final addition of moisture. The oil is added continuously from a reservoir directly over the mill. The amount to be added will vary from 3 qt. to 5 gal. per hour, dependent upon the tonnage of iron poured.

51. Fuel oil can be added to the rebonding mixtures in the same manner in which it is added to the facing sand mixtures. The mois-

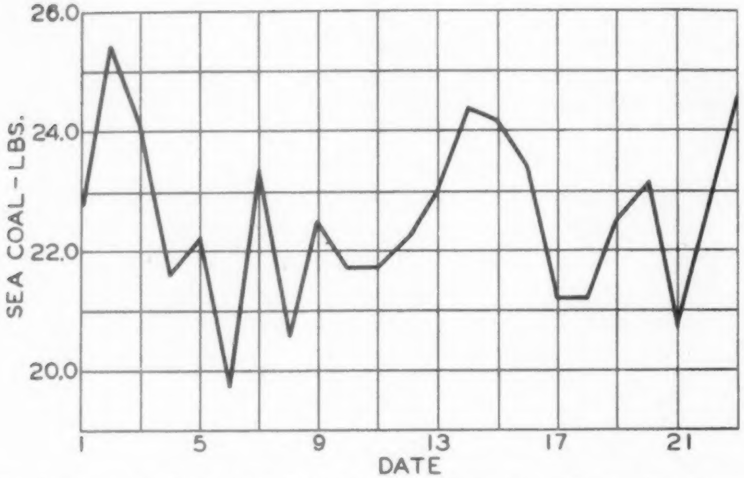

FIG. 1—POUNDS OF SEACOAL PER TON OF IRON PER DAY'S OPERATION FOR ONE MONTH.

ture contents of the rebonding mixtures can be reduced considerably if some fuel oil is used. This helps to eliminate the formation of segregations of clay and seacoal.

52. All three methods of adding the fuel oil to the foundry sand give equally satisfactory results. The usual amount of care must be observed in mixing to obtain a uniform mixture.

EFFECT OF FUEL OIL ON SAND PROPERTIES

53. Certain definite improvements in the properties of molding sand are obtained by the use of fuel oil:

(1) Increases the amount of V.C.M.
(2) Aids in obtaining proper temper.
(3) Prevents sand from sticking to the pattern.
(4) Reduces rate at which sand will dry out.
(5) Reduces amount of seacoal.

54. Fuel oil is very nearly 100 per cent volatile matter. By the addition of fuel oil to the foundry sand, the V.C.M. is increased directly in proportion to the amount added. A small amount of petroleum coke is produced during the pouring cycle. This increased amount of V.C.M., plus the petroleum coke, aids in equalizing the expansion and contraction of the foundry molding sand at elevated temperatures. This aids in the elimination of buckles in the mold. It is particularly effective on castings having large surface areas, such as stove plate.

55. Through the addition of fuel oil to the system sand, it has been possible to reduce the moisture content about 0.5 per cent. This has proved particularly advantageous because, by doing so, we can more nearly approach the optimum moisture content. This has not only effected a saving in the amount of clay bond used, but has also helped increase the permeability of the foundry sand.

56. There seems to be less of a tendency of the oiled sand to dry out in the sand hoppers. This is probably due to the emulsifying of the oil and water in the mixing operations. Battelle Memorial Institute, Columbus, Ohio, is conducting tests at the present time on this condition. The figures are not yet available.

SAVINGS EFFECTED

57. Since the practice of adding fuel oil to the foundry sand was started, the amount of seacoal added has been reduced about 30 per cent. This is quite a substantial saving in seacoal.

58. Figure 1 shows the pounds of seacoal used per ton of iron per day's operation. This shows during this particular month's operation, a maximum of 25 lb. of and a minimum of 19 lb. of seacoal per ton of iron.

59. Figure 2 shows the pints of fuel oil used per ton of iron during the same period. The maximum amount of oil used was 3.5 pints, the minimum 2.7 pints. From these graphs, it will be noted that both the pounds of seacoal and the pints of fuel oil used per ton of iron were quite constant.

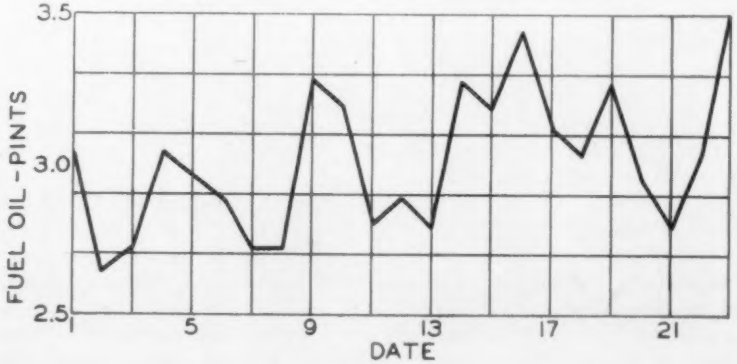

FIG. 2—PINTS OF FUEL OIL USED PER TON OF IRON CAST DURING THE SAME PERIOD AS USED TO COMPILE THE CHART IN FIG. 1.

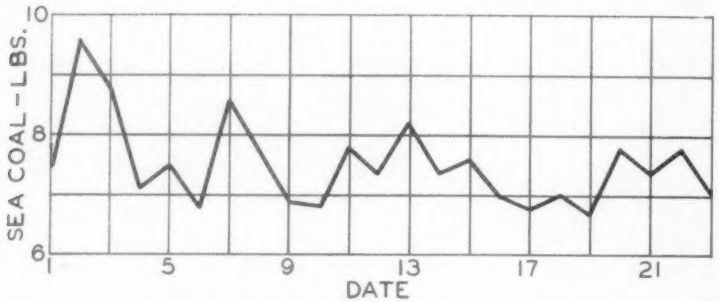

FIG. 3—SEACOAL USED PER PINT OF FUEL OIL USED DURING THE SAME PERIOD AS USED TO COMPILE THE CHARTS IN FIGS. 1 AND 2.

60. Figure 3 shows the pounds of seacoal used per pint of fuel oil. A maximum of 9.6 lb. and a minimum of 6.7 lb. of seacoal were used per pint of fuel oil during this period. The average for the month was 7.5 lb. of seacoal per pint of fuel oil. Since a pint of oil weighs about one pound, the ratio by weight was 7.5 lb. of seacoal to one pound of fuel oil.

CONCLUSION

61. It has not been the intent of the writer to show any new and startling developments in the use of seacoal and fuel oil. The aim of the writer has been merely to give a general review of the properties and uses of seacoal and fuel oil in a fairly simple manner in order that the functions of these two ingredients in foundry molding sand might be more clearly understood by the ordinary foundryman.

DISCUSSION

Presiding: DR. H. RIES, Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

Co-Chairman: H. A. DEANE, Brake Shoe & Castings Div., American Brake Shoe & Foundry Co., New York, N. Y.

A. J. HEYSEL[1] (*written discussion*): The author states that this development or experiment is comparatively new but that in some instances it was known as long as ten years ago. In this respect the writer wishes to point out that back in 1921 while the writer was connected with the Standard Plant of the American Radiator Co. in this city as an apprentice molder, we put forth the theory that the same action or result ob-

[1] E. J. Woodison Co., Buffalo, N. Y.

tained from the use of seacoal should also be obtained for the same reason from a crude mineral oil. To prove this theory, an associate and the writer proceeded to spray the mold faces of the copes and drags used in the manufacture of wall type radiators with excellent results. In most cases, the finish on the surfaces of these radiators was even smoother than some of those produced with the use of seacoal, and, in addition, we noticed that the spraying of this crude oil had a tendency to prevent too rapid evaporation of moisture from the molding sand and thereby helped retain the green strength.

The only equipment used for this was an ordinary air hose hooked to a sprayer of about one or 2 qt. capacity, and the faces of the molds were covered sparingly with this fine spray of oil. Cores were then placed in the mold, and the mold was closed and poured soon after the closing.

The writer merely brings this to your attention to show that as far back as 21 years ago this experiment was tried but further development of this method was postponed due to the rush of business.

L. B. OSBORN[2]: Regarding the effect of seacoal, I do not know to just what extent Mr. Zirzow was considering the moisture of the sand on which the hot strengths were taken, but in some laboratory work that we did, it was our conclusion that, in general, the hot strengths were lowered, provided the sand with seacoal was tempered to the same moisture as when tested without seacoal. If the sands were held at the same moisture, our general observations were that the hot strengths would be less, especially in the higher temperature ranges.

MR. ZIRZOW: I am not disputing that fact, but I will say that these tests were run on sand prepared for use in the foundry, with the seacoal in it, and, therefore, we were using a higher moisture content.

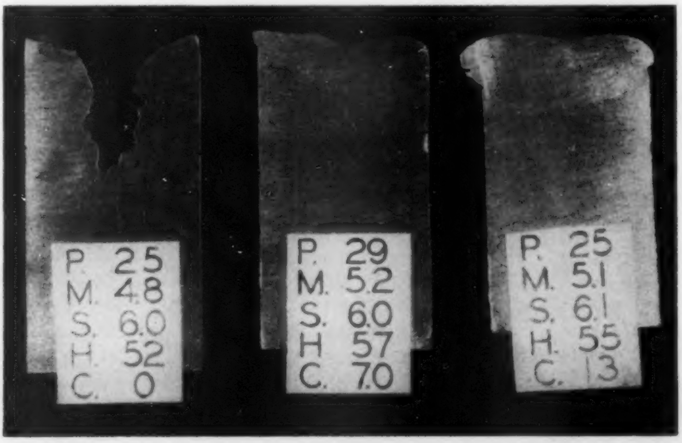

FIG. 4—RELATION BETWEEN SEACOAL CONTENT AND PIPING TENDENCY. TOP SECTIONS OF 1.2 x 8-IN. CAST IRON BARS POURED IN OPEN MOLDS.

[2] Hougland & Hardy, Inc., Evansville, Ind.

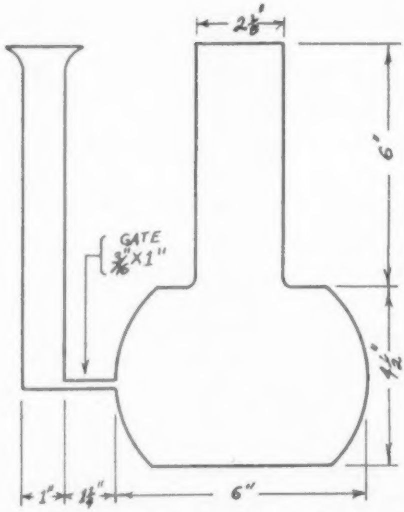

FIG. 5—HEAVY SECTION CASTING FOR SHRINKAGE TESTS.

MR. OSBORN: I think the practical use in the foundry would bear out your statement, as the practical moisture content would nearly always be higher than the laboratory ideal moisture.

MR. ZIRZOW: There has to be more moisture in the sand to compensate for the fine seacoal being added, which perhaps offsets some of the beneficial effects accomplished by the seacoal. Because more moisture must be added, there is more steam, and we all know water is perhaps the most dangerous thing we have in our sand for green sand molding.

C. P. ALBUS[3]: We have found that at a constant moisture content of 4 per cent, the addition of 5 per cent seacoal to a lake sand of a fineness of 55, bonded with 2.5 per cent western bentonite and 2.5 per cent southern bentonite, increased the hot strength at temperatures of 500° to 2000°F. At 2000°F., hot strength had fallen to a value less than that of sand and clay alone.

MR. ZIRZOW: What was the moisture content?

MR. ALBUS: Four per cent.

MR. ZIRZOW: That is enough to temper molding sand. In other words, you had a molding sand, with optimum moisture content for strength.

MR. ALBUS: We tried to use an average moisture content that is being employed by foundries for tempering molding sands.

H. WOMOCHEL[4]: I would like to include in this discussion some illustrations made in connection with work we are doing on molding sands at Michigan State.

Figure 4 shows three castings, all poured from the same ladle. The

[3] Hercules Powder Co., Wilmington, Del.
[4] Engineering Experiment Station, Michigan State College, East Lansing, Michigan.

casting on the left was made in a mold containing no seacoal. The mold for the casting in the center contained 7 per cent seacoal, and the one on the right contained 13 per cent. One can see the effect the addition of seacoal had on apparent shrinkage. When the seacoal was added, the piping in the riser disappeared almost completely.

We conducted some experiments of a similar nature on castings of heavy section. The section size is shown in Fig. 5. This casting was in the form of a ball flattened at the top and bottom, with a riser as indicated.

Figure 6 shows castings from three different kinds of molds, all of which were poured from the same ladle. The casting on the left was made in green sand containing no seacoal. The casting in the center was made in green sand containing 7 per cent seacoal, the same green sand as the other castings, modified slightly to take care of the effect of the addition of seacoal on permeability. The third was poured in a dry sand core. The seacoal was effective in reducing the amount of piping in the riser.

These effects of seacoal are reproducible. We have conducted a large number of these experiments, and we always get the same results, sometimes to a smaller degree than indicated here, but always in the same direction. These experiments have been checked in other foundries. For example, a jobbing foundry was having trouble with a small casting poured in molds from a heap of sand containing no seacoal. The difficulty was shrinkage and sinking of the cope face of the casting. The job was transferred to a heap containing seacoal in the usual amounts and the difficulties with shrinkage disappeared.

J. A. DUMA[5]: Where did the shrinkage go?

MR. WOMOCHEL: We cannot be certain. We are more interested in

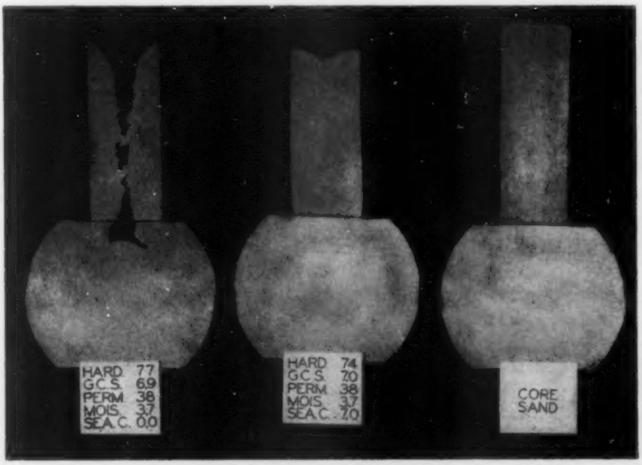

FIG. 6—CORE SAND COMPARED WITH GREEN SAND, WITH AND WITHOUT SEACOAL.

[5] Norfolk Navy Yard, Portsmouth, Va.

establishing the fact that the mold does have an effect on shrinkage. The size and distribution of shrinkage defects was influenced by almost anything we did to the mold in our experiments. The hardness with which we rammed the mold, the moisture content, and the clay content all changed the size and distribution of shrinkage defects. Why that is, we are not prepared to say. We have some ideas but no proof. We think, however, that some so-called shrinkage defects are caused by changes in the dimensions of the mold cavity subsequent to pouring the castings. We think various mold materials either expand or give under the action of the temperature and ferrostatic pressure in the molds.

The Effect of Phosphorus on the Growth of Gray Cast Iron†

By M. N. Dastur* and Morris Cohen*, Cambridge, Mass.

Abstract

A series of cast irons ranging in phosphorus content from 0.05 to 1.0 per cent was subjected to growth tests in air and in lead above and below the eutectoid transformation temperature. Chromium and chromium-molybdenum irons were included for comparison purposes. The tests were designed to reveal the cause as well as the magnitude of the growth effects. After each of ten different treatments, the irons were examined microscopically, and were analyzed for graphitic and total carbon in order to ascertain the extent of graphitization and the loss of carbon due to oxidation. The growth was determined by specific volume measurements which eliminated such disturbing factors as scale formation, warpage and dissimilar expansions in different directions.

The results of this investigation indicate that growth is mainly due to graphitization and attendant cracking, eutectoid transformation cracking, and oxidation effects. The relative magnitude of these effects has been roughly determined. Phosphorus improves the growth resistance of cast iron by inhibiting each of these three causes of growth.

1. Cast iron generally undergoes a permanent increase in volume as a result of heating to elevated temperatures. This phenomenon of growth is of considerable industrial importance because the service life of gray iron castings, such as ingot molds, annealing boxes and grate-bars, may be seriously limited by the excessive changes in dimensions and by the deterioration of mechanical properties which accompany growth. Consequently, it is not surprising to find that many investigations have been directed at the practical

† This paper is based on a thesis submitted by M. N. Dastur in partial fulfillment of the requirements for the degree of Master of Science in Metallurgy at the Massachusetts Institute of Technology, Cambridge, Massachusetts, October, 1941.

* Department of Metallurgy, Massachusetts Institute of Technology.

Note: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

problem of inhibiting the growth of cast iron and also at the scientific problem of ascertaining the basic reasons for growth. It is now known, for example, that nickel, chromium and silicon, if present in sufficient amounts, are particularly effective in retarding the growth of cast iron, and several growth-resisting irons containing these elements have been developed.

2. This paper describes the results of some experiments on the effect of phosphorus on the growth of cast iron. Despite the fact that phosphorus is one of the common elements in cast iron, the literature does not clearly show whether phosphorus is beneficial or detrimental in retarding growth. Andrew and Higgins[1] claim that phosphorus increases growth materially, while the observations of Carpenter[2] and of Kennedy and Oswald[3] indicate that phosphorus is a potent growth inhibitor. The latter point of view is more or less supported by the work of Sohnchen and Piwowarsky[4] who found that phosphorus decreases the growth of cast iron on heating in air, but has no marked effect when the heating is carried out in vacuo. Most other investigators have paid little attention to the influence of phosphorus on growth. Accordingly, in the present research, it was considered advisable to undertake a series of systematic growth tests on cast irons containing variable phosphorus contents so that the effect of phosphorus could be studied in detail. All of the growth experiments were designed to reveal the cause as well as the magnitude of the growth effects.

EXPERIMENTAL DETAILS

3. Six cast irons were prepared in a 150-lb. high frequency furnace. The base metal of all the heats was cupola iron of the following composition: total carbon, 4.17 per cent; graphitic carbon, 3.41 per cent; silicon, 2.08 per cent; manganese, 1.07 per cent; sulphur, 0.03 per cent; phosphorus, 0.112 per cent. The other ingredients were wash metal (carbon, 3.35 per cent; silicon, 1.10 per cent), 25 per cent ferrophosphorus, 71 per cent ferrochromium, 60 per cent ferromolybdenum and 75 per cent ferrosilicon. Castings, 9-in. long by 1¼-in. in diameter, were poured into sand molds. In order to avoid possible surface effects, the castings were machined down to ⅜-in. in diameter. Specimens, ½-in. long, were cut from these bars for the growth tests. Table 1 gives the chemical analyses of the six irons investigated. Irons A, B, C and D represent a series with phosphorus contents ranging progressively from about

[1] Superior numbers refer to bibliography at end of paper.

0.05 to 1.0 per cent, while irons E and F containing chromium and chromium-molybdenum with constant phosphorus were included for comparison purposes.

Table 1

CHEMICAL ANALYSES OF THE CAST IRONS

Iron	*T. C.*	*G. C.*	*Si*	*P*	*Mn*	*S*	*Cr*	*Mo*
A	3.40	2.78	2.03	0.067	0.45	0.026		
B	3.49	3.04	2.11	0.13	0.67	0.023		
C	3.36	2.69	2.01	0.53	0.49	0.026		
D	3.21	2.70	1.98	0.94	0.53	0.023		
E	3.35	2.63	2.01	0.20	*	*	0.48	
F	3.29	2.51	2.02	0.19	*	*	0.48	0.48

4. The growth runs were carried out in an oxidizing atmosphere (air) and in an inert atmosphere (well-deoxidized lead bath) at a subcritical temperature of 1250°F. and at a super-critical temperature of 1500°F. Duplicate specimens of the six irons were subjected to the following treatments:

Treatment IA—Continuous heating for 24 hours at 1250°F. in air; slow cooling to room temperature.

Treatment IL—Same as IA, but in lead bath.

Treatment IIA—Heating for 4 hours at 1250°F. in air; slow cooling to room temperature. Cycle repeated five more times to give accumulated time of 24 hours at 1250°F.

Treatment IIL—Same as IIA, but in lead bath.

Treatment IIIA—Continuous heating for 24 hours at 1500°F. in air; slow cooling to room temperature.

Treatment IIIL—Same as IIIA, but in lead bath.

Treatment IVA—Heating for 4 hours at 1500°F. in air; slow cooling to room temperature. Cycle repeated five more times to give accumulated time of 24 hours at 1500°F.

Treatment IVL—Same as IVA, but in lead bath.

Treatment VA—Heating for 4 hours at 1500°F. in air; slow cooling to 1250°F. for 2 hours. Cycle repeated five more times to give accumulated time of 24 hours at 1500°F. Slow cooling to room temperature after last cycle.

Treatment VL—Same as VA, but in lead bath.

5. After each of the above treatments, the six cast irons were analyzed for graphitic carbon and total carbon in order to determine the extent of graphitization and loss of carbon. The microstructures also were examined. The extent of growth was measured

* Not Estimated.

by the increase in the specific volume of the specimens. It has been common practice to ascertain the growth of cast iron by means of a dilatometer or by observing the length and diameter of a test bar before and after treatment. Calculations of volume changes based on such measurements are open to question because of scale-formation, warpage, and dissimilar expansions in different directions. These difficulties are naturally avoided by using the specific volume method, since the scale is first removed and the volume of the remaining specimen per unit weight is determined by the Archimedes' Principle without regard to the external shape and dimensions of the specimen.

6. It is important to note, however, that cast iron becomes somewhat porous as a result of growth, and this growth is properly evaluated not by the changes in the *true* specific volume, but by the changes in the *apparent* specific volume which includes the internal pores and cracks. In measuring specific volumes by the usual method of weighing in air and in water, water is partially absorbed by porous specimens, and the calculated specific volume lies somewhere between the true and apparent values. Kikuta[5] attempted to correct for the absorbed water by weighing the specimens in air, then in water, and finally in air with the absorbed water. While this procedure theoretically permits the calculation of the apparent specific volume, the last weighing is subject to considerable error because the superficial water must be removed, and this cannot be done without the loss of some of the absorbed water.

7. In the present investigation, it was decided to prevent the absorption of water during the water-weighings so that accurate determinations of the apparent specific volumes could be obtained. This was accomplished with the aid of glyptol paint which provided a tightly adherent waterproof coating. The oxide scale formed on the specimens during heating in air was completely removed by sand blasting before any weighings were made. In fact, for the sake of uniformity, all the specimens were sand blasted whether scale was present or not. Four weighings were necessary to evaluate the apparent specific volume of each specimen and to correct for the volume of the glyptol paint: (1) the weight of the specimen in air, (2) the weight of the specimen plus the glyptol coating in air, (3) the weight of the specimen plus the coating plus the suspension* in distilled water, and (4) the weight of the suspension alone

* When weighed in water, the specimens were held in a copper wire cage suspended from a fine platinum wire.

in water. The precision of the weighings in water was materially enhanced by the addition of a trace of wetting reagent (sorbitol laurate) to the distilled water, which reduced the surface tension on the platinum wire. Weighings were easily reproducible to $\pm$ 0.5 milligrams. The apparent specific volume was then calculated as follows:

$$\text{Apparent specific volume} = \frac{\text{Volume of specimen}}{\text{Weight of specimen}} \tag{1}$$

$$= \frac{\text{Volume of coated specimen} - \text{volume of coating}}{\text{Weight of specimen}} \tag{2}$$

$$= \frac{\dfrac{T - (R-P)}{D_w} - \dfrac{T - S}{D_g}}{S} \tag{3}$$

where T = weight of specimen plus coating in air,
R = weight of specimen plus coating plus suspension in water,
P = weight of suspension in water,
S = weight of specimen alone in air,
D_w = density of water at temperature of measurement.
D_g = density of glyptol (taken as 1.010)**.

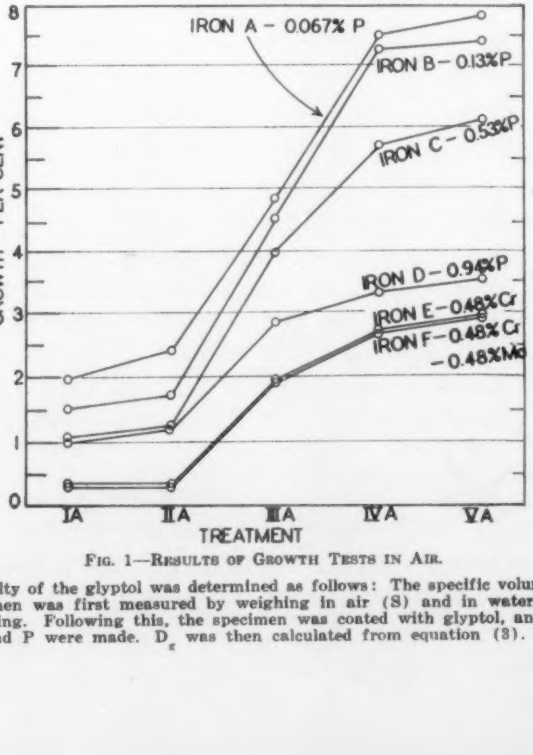

FIG. 1—RESULTS OF GROWTH TESTS IN AIR.

** The density of the glyptol was determined as follows: The specific volume of a non-porous specimen was first measured by weighing in air (S) and in water without the aid of a coating. Following this, the specimen was coated with glyptol, and the weighings T, R, and P were made. D_g was then calculated from equation (3).

8. The specific volume measurements were carried out before and after the various heating cycles, and the growth values have been expressed as per cent increase in volume.

EXPERIMENTAL RESULTS

9. The results of the growth tests carried out in the oxidizing atmosphere are illustrated graphically in Fig. 1. The curves show that *in air*:

(1) The growth after all the treatments becomes less as the phosphorus content is increased. However, one-half per cent chromium is more effective than one per cent phosphorus in retarding growth. The addition of one-half per cent molybdenum to the chromium iron does not further improve the growth resistance.

(2) Growth at 1250°F. is practically the same whether the heating is continuous or repeated.

(3) Compared to the growth which occurs at 1250°F., there is an appreciable increase in growth as a result of continuous heating at 1500°F.

(4) There is a further increase in growth due to repeated heating at 1500°F.

(5) Cyclic heating between 1500° and 1250°F. produces only slightly more growth than repeated heating at 1500°F.

10. The results of the growth tests carried out in the lead bath are shown in Fig. 2. It is evident that in an *inert atmosphere*:

(1) Phosphorus retards growth after all the treatments, but is not as effective as chromium. The addition of one-half per cent molybdenum to the chromium iron has no effect on the growth resistance.

(2) Growth is practically the same for continuous and repeated heating at 1250°F. and for continuous heating at 1500°F.

(3) Compared to these three treatments, repeated heating at 1500°F. causes a marked increase in growth.

(4) Cyclic heating between 1500° and 1250°F. produces practically no more growth than does repeated heating at 1500°F.

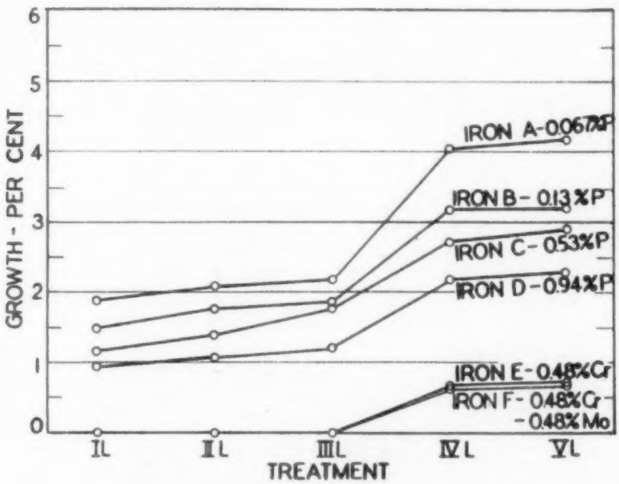

FIG. 2—RESULTS OF GROWTH TESTS IN LEAD.

(5) Growth at 1250°F. in air is only slightly greater than in lead, but growth at 1500°F. in air is very much greater than in lead.

11. The increase in growth resistance due to phosphorus is demonstrated more clearly in Figs. 3 and 4. The growth of iron D (0.94 per cent phosphorus) after each treatment is roughly one-half the growth experienced by iron A (0.067 per cent phosphorus).

12. Tables 2 and 3 give the total, graphitic and combined carbon contents of the six irons before and after the various treatments in air and in lead. The decrease in the combined carbon may be taken as a measure of the extent of graphitization. According to Table 2, a small amount of graphitization and loss of total carbon occurs in the phosphorus iron series on heating in air at 1250°F. There is no corresponding effect in the two alloy irons. The 1500°F. treatments in air result in considerable graphitization and carbon loss in all of the irons with the extent of these carbon changes tending to become less, the higher the phosphorus content. Among the 1500°F. treatments, it is quite evident that repeated and cyclic heating cause much higher carbon loss than continuous heating. The two alloy irons exhibit the least graphitization and loss of carbon.

13. The chemical analyses in Table 3 demonstrate that no car-

Table 2

TOTAL CARBON, GRAPHITIC CARBON AND COMBINED CARBON CONTENTS* OF THE IRONS BEFORE AND AFTER HEAT TREATMENT IN AIR

Iron		Before Treatment			After Treatment IA: Continuous heating, 1250°F.			IIA: Repeated heating, 1250°F.			IIIA: Continuous heating, 1500°F.			IVA: Repeated heating, 1500°F.			VA: Cyclic heating, 1500°F.—1250°F.		
		T. C.	G. C.	C. C.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.
A	(0.067 per cent P)	3.40	2.78	0.62	3.15	2.82	0.33	3.10	2.94	0.16	2.63	2.52	0.11	1.61	1.57	0.04	1.47	1.45	0.02
B	(0.13 per cent P)	3.49	3.04	0.45	3.28	3.02	0.26	3.36	3.12	0.24	2.68	2.61	0.07	1.47	1.44	0.03	1.46	1.44	0.02
C	(0.58 per cent P)	3.36	2.69	0.67	3.27	2.78	0.49	3.15	2.81	0.34	2.70	2.51	0.19	1.55	1.35	0.20	1.44	1.32	0.12
D	(0.94 per cent P)	3.21	2.70	0.51	3.23	2.76	0.47	3.17	2.79	0.38	2.73	2.62	0.11	1.98	1.90	0.08	1.97	1.73	0.24
E	(0.48 per cent Cr)	3.35	2.63	0.72	3.34	2.59	0.75	3.35	2.61	0.74	2.80	2.43	0.37	2.87	2.65	0.22	2.73	2.34	0.39
F	(0.48 per cent Cr) (0.48 per cent Mo)	3.29	2.51	0.78	3.35	2.50	0.85	3.31	2.56	0.75	—	—	—	3.03	2.59	0.44	—	—	—

* The irons were analyzed for total carbon and graphitic carbon. The combined carbon contents are taken by difference.

Table 3

TOTAL CARBON, GRAPHITIC CARBON AND COMBINED CARBON CONTENTS* OF THE IRONS BEFORE AND AFTER HEAT TREATMENT IN LEAD

Iron	*Before Treatment*			*After Treatment* IL: Continuous heating, 1250° F.			IIL: Repeated heating, 1250° F.			IIIL: Continuous heating, 1500° F.			IVL: Repeated heating, 1500° F.			VL: Cyclic heating, 1500° F.—1250° F.		
	T. C.	*G. C.*	*C. C.*	*T. C.*	*G. C.*	*C. C.*	*T. C.*	*G. C.*	*C. C.*	*T. C.*	*G. C.*	*C. C.*	*T. C.*	*G. C.*	*C. C.*	*T. C.*	*G. C.*	*C. C.*
A (0.067 per cent P)	3.40	2.78	0.62	3.40	3.06	0.34	3.42	3.16	0.26	3.40	3.05	0.35	3.38	3.11	0.27	3.44	3.20	0.24
B (0.13 per cent P)	3.49	3.04	0.45	3.36	3.12	0.24	3.41	3.26	0.15	3.49	3.28	0.21	3.42	3.23	0.19	3.46	3.30	0.16
C (0.58 per cent P)	3.36	2.69	0.67	3.34	2.89	0.45	3.35	2.98	0.37	3.39	3.00	0.39	3.35	3.03	0.32	—	—	—
D (0.94 per cent P)	3.21	2.70	0.51	3.17	2.81	0.36	3.15	2.96	0.19	3.28	2.98	0.30	3.22	3.03	0.19	3.22	3.07	0.15
E (0.48 per cent Cr)	3.35	2.63	0.72	3.38	2.61	0.77	3.38	2.73	0.65	3.24	2.83	0.41	3.31	3.06	0.25	3.29	3.05	0.24
F {(0.48 per cent Cr) (0.48 per cent Mo)}	3.29	2.51	0.78	3.20	2.53	0.67	—	—	—	3.29	2.92	0.37	3.27	3.01	0.26	—	—	—

* The irons were analyzed for total carbon and graphitic carbon. The combined carbon contents are taken by difference.

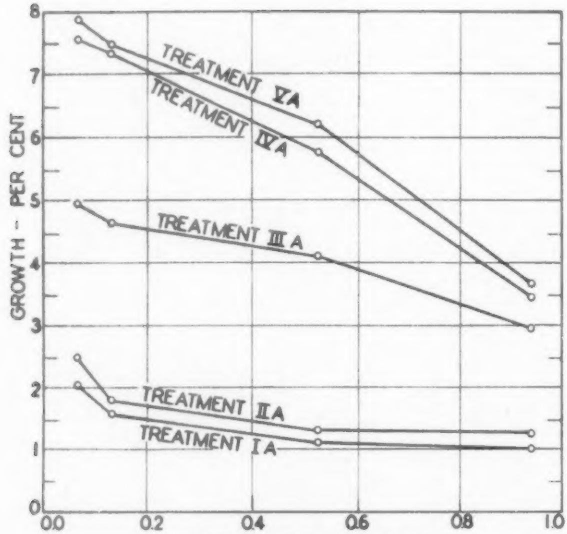

FIG. 3—EFFECT OF PHOSPHORUS ON GROWTH IN AIR.

bon was lost from any of the irons after the treatments in lead. In general, the graphitization which occurs at 1250°F. is about the same in lead as in air. On the other hand, at 1500°F., the irons undergo more graphitization in air than in lead.

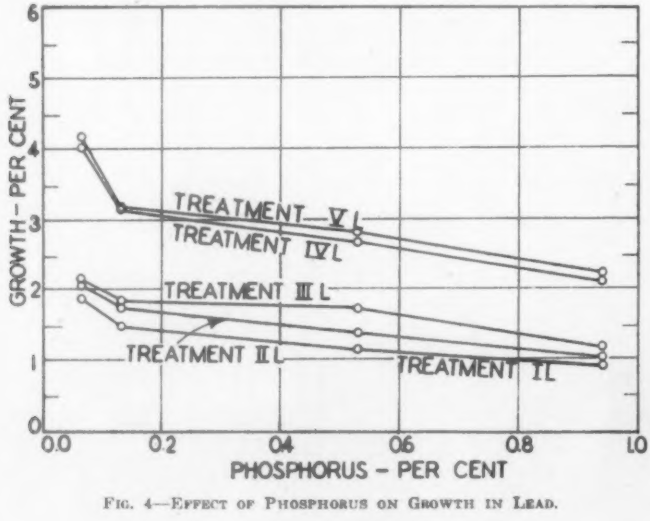

FIG. 4—EFFECT OF PHOSPHORUS ON GROWTH IN LEAD.

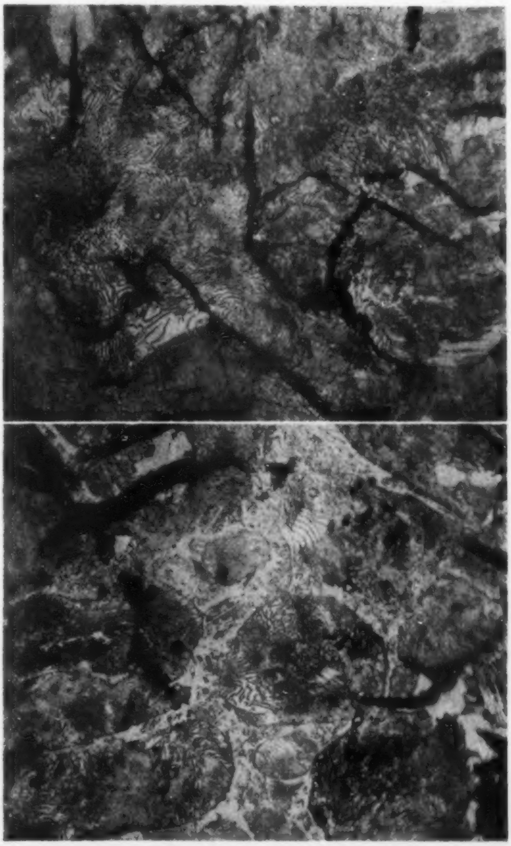

FIG. 5—(TOP) MICROSTRUCTURE OF IRON A (0.067% P) AS CAST. NITAL ETCH. X350. FIG. 6—(BOTTOM) MICROSTRUCTURE OF IRON D (0.94% P) AS CAST. NITAL ETCH. X350.

14. Typical microstructures of irons A and D before and after various treatments are shown in Figs. 5 to 12. In the cast state, all of the irons displayed a uniform dispersion of graphite flakes in a pearlitic matrix, and the steadite constituent increased progressively with the phosphorus content (cf. Figs. 5 and 6). The changes in structure after heating at 1250°F. in lead are illustrated by Figs. 7 and 8 in which the combined carbon associated with the original pearlitic matrix has been largely graphitized. No significant change was noted in the steadite structure.

15. Heating at 1500°F. in lead produced similar structures with the visible extent of graphitization more or less in proportion to the change indicated by the chemical analyses. On heating at 1500°F.

in air, however, a marked difference in the microstructure was observed. The metal around the graphite flakes exhibited signs of oxidation, and much of the graphite was burned out (Figs. 9 to 11). Both of these oxidation phenomena decreased in magnitude with increasing phosphorus content, as is evident from a comparison of Figs. 9 and 10. The penetration of the oxygen took place principally along the channels formed by the graphite pockets and interconnecting cracks, but there was also some diffusion of the oxygen through the matrix to reach regions in between the channels, as shown in Fig. 11.

16. The low magnification pictures in Fig. 12 illustrate the

FIG. 7—(TOP) MICROSTRUCTURE OF IRON A (0.067% P) AFTER CONTINUOUS HEATING AT 1250°F. IN LEAD (TREATMENT I L). NITAL ETCH. X350. FIG. 8—(BOTTOM) MICROSTRUCTURE OF IRON D (0.94% P) AFTER CONTINUOUS HEATING AT 1250°F. IN LEAD (TREATMENT I L). NITAL ETCH. X350.

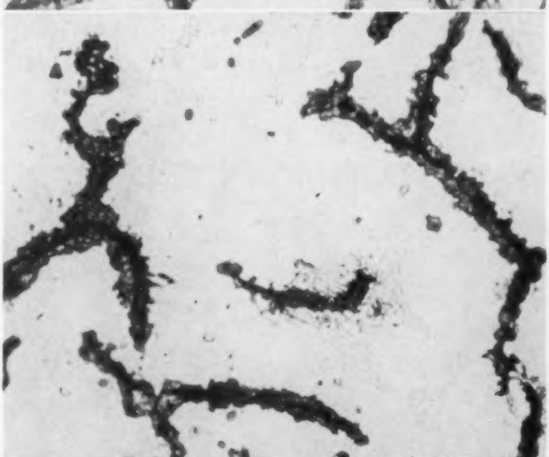

FIG. 9—(TOP) MICROSTRUCTURE OF IRON A (0.067% P) AFTER CONTINUOUS HEATING AT 1500°F. IN AIR (TREATMENT III A). NITAL ETCH. X350. FIG. 10—(BOTTOM) MICROSTRUCTURE OF IRON D (0.94% P) AFTER CONTINUOUS HEATING AT 1500°F. IN AIR (TREATMENT III A). NITAL ETCH. X350.

depth of oxidation in irons A and D after continuous heating at 1250°F., continuous heating at 1500°F., and repeated heating at 1500°F. Oxidation at 1250°F. was negligible compared to that observed at 1500°F. The inward penetration of the oxidation effects decreased with increasing phosphorus content, and for any given iron, was greater after repeated and cyclic heating than after continuous heating.

DISCUSSION OF RESULTS

Growth Below the Critical Temperature

17. Since the growth which occurs in all the irons on heating at 1250°F. for 24 hours is little affected by the type of atmosphere and the number of heating cycles, it is evident that internal oxidation, gaseous penetration and cracking due to thermal stresses* play minor roles in the growth of cast iron during such heating. Furthermore, possible permament volume changes resulting from the eutectoid transformation are ruled out as a factor in this growth because the heating is confined to sub-critical temperatures. On the other hand, both the chemical analyses and the microstructures indicate that appreciable decomposition of the combined carbon takes place in the phosphorus irons during heating at 1250°F., and this graphitization appears to be the primary cause of sub-critical growth. However, the measured growth values are actually greater than those calculated from the observed amounts of graphitization. Based on the relative volumes[6] of iron carbide, ferrite and graphite, the graphitization of 1 per cent of carbon should produce a 2 per cent increase in volume; yet, as shown in Table 4, the measured

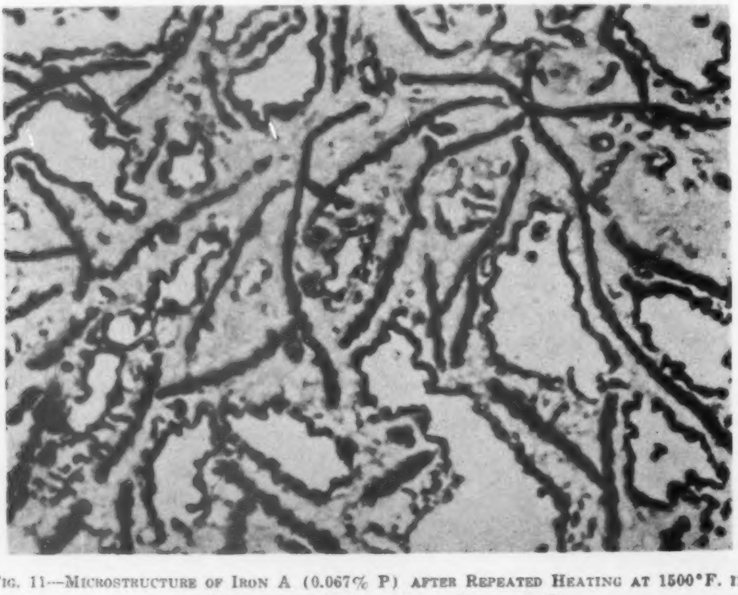

FIG. 11—MICROSTRUCTURE OF IRON A (0.067% P) AFTER REPEATED HEATING AT 1500°F. IN AIR (TREATMENT IVA). NITAL ETCH. 350X.

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* Thermal stresses may arise from uneven heating and cooling and from the different expansion coefficients of the various microconstituents.

growth per unit of carbon graphitized is considerably greater in each of the four phosphorus irons than the theoretical 2 per cent*. These relatively large growth values obtained under conditions where graphitization is the only likely factor at play suggest that internal cracking accompanies the graphitization process. Such cracks were actually found, as shown in Fig. 13. Careful polishing was necessary to reveal these cracks because they tended to become filled with polishing debris and flowed metal. Yet, the use of an etching reagent for cleaning out these cracks had to be avoided because they might then be mistaken for the ferrite grain boundaries brought out by the etching. In view of these cracks, it appears likely that the rupture-strength of the cast iron matrix is exceeded by the formation of the voluminous graphite, and the resulting cracks cause greater growth than is attributable to the graphitization as such.

18. According to Table 4, phosphorus inhibits the growth (column 3) of cast iron below the critical range in two ways: (1) phosphorus reduces the degree of graphitization (column 4), and (2) phosphorus decreases the extent of growth per unit of carbon graphitized (column 5). The first factor signifies that phosphorus helps keep the carbon in the non-graphitic form, while the second factor indicates that phosphorus strengthens the matrix of the iron so as to resist the internal cracking which attends graphitization. In fact, both Bain[7] and Bullens[8] report that phosphorus is one of the most potent ferrite strengtheners of all the common alloy elements. Furthermore, Tapsell[9] has shown that ordinary cast iron with 0.72 per cent phosphorus is superior to many alloy irons in both strength and ductility at elevated temperatures.

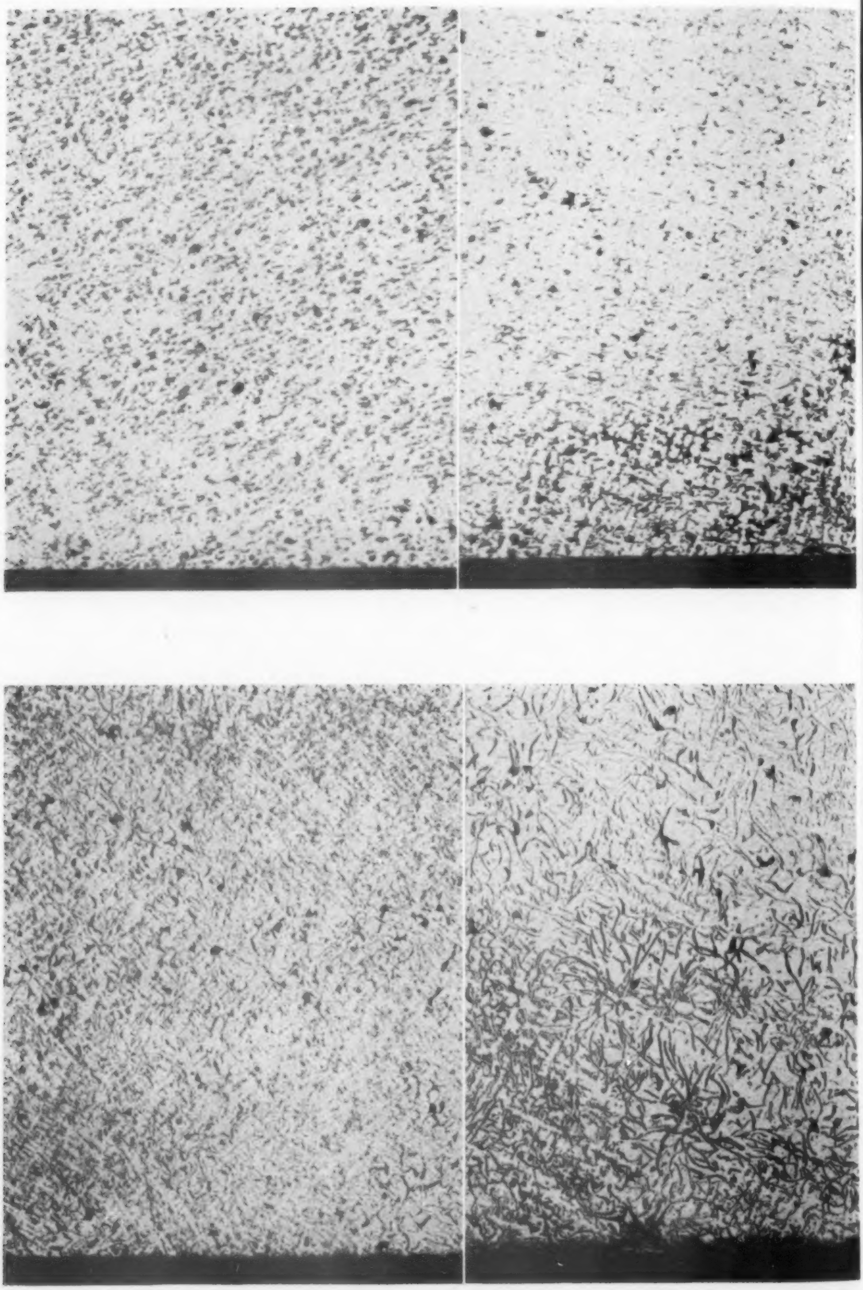
Table 4

Relationship Between Growth and Graphitization on Heating in Lead at 1250°F. for 24 Hours

(Data Averaged for Continuous and Repeated Heating)

Iron	*Per Cent Phosphorus*	*Per Cent Growth*	*Per Cent Carbon Graphitized*	*Per Cent Growth per Per Cent Carbon Graphitized*
A	0.067	1.97	0.32	6.2
B	0.13	1.61	0.27	6.0
C	0.53	1.26	0.26	4.9
D	0.94	1.00	0.22	4.6

* This comparison cannot be made in the case of the two alloy irons E and F because they underwent virtually no growth or graphitization at 1250°F. in lead.



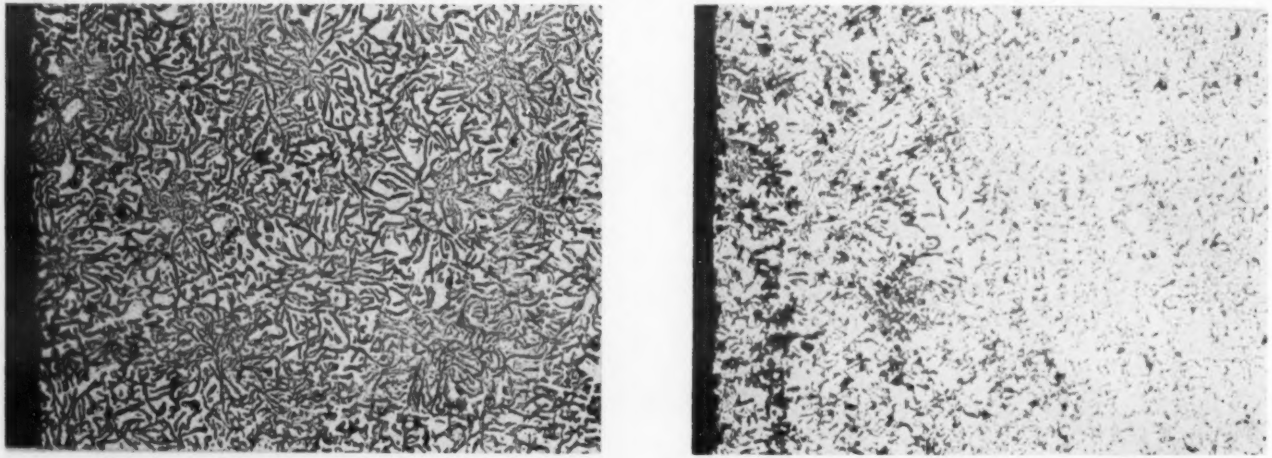


FIG. 12—MICROSTRUCTURES OF IRONS A (0.067% P) AND D (0.94% P) SHOWING EXTENT OF OXYGEN PENETRATION. NITAL ETCH. x25.

A. (LEFT TOP) IRON A AFTER CONTINUOUS HEATING AT 1250°F. IN AIR (TREATMENT I A)
B. (LEFT CENTER) IRON A AFTER CONTINUOUS HEATING AT 1500°F. IN AIR (TREATMENT III A)
C. (LEFT BOTTOM) IRON A AFTER REPEATED HEATING AT 1500°F. IN AIR (TREATMENT IV A)
D. (RIGHT TOP) IRON D AFTER CONTINUOUS HEATING AT 1250°F. IN AIR (TREATMENT I A)
E. (RIGHT CENTER) IRON D AFTER CONTINUOUS HEATING AT 1500°F. IN AIR (TREATMENT III A)
F. (RIGHT BOTTOM) IRON D AFTER REPEATED HEATING AT 1500°F. IN AIR (TREATMENT IV A)

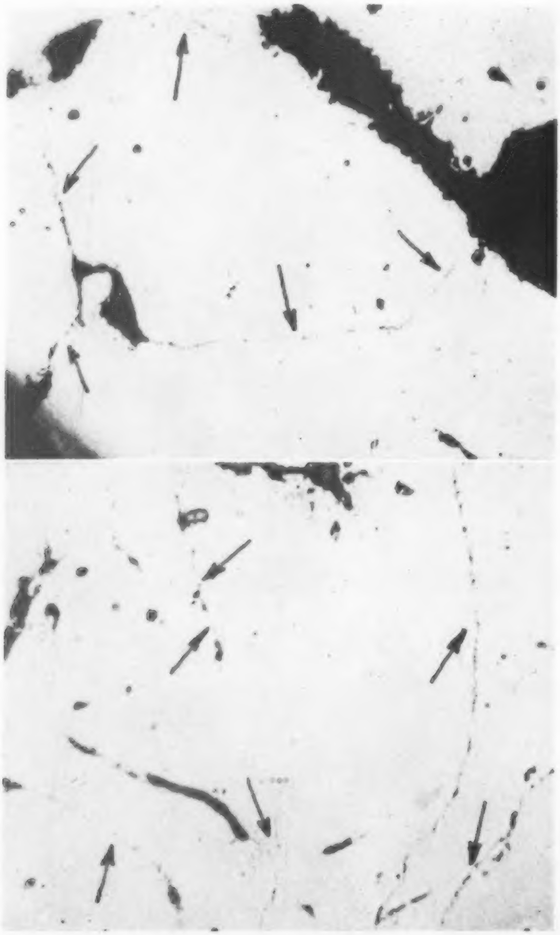


FIG. 13—(TOP) MICROSTRUCTURE OF IRON A (0.067% P) AFTER CONTINUOUS HEATING AT 1250°F. IN LEAD (TREATMENT I L) SHOWING FINE CRACKS IN MATRIX. UNETCHED. X500.
FIG. 14—(BOTTOM) MICROSTRUCTURE OF IRON A (0.067% P) AFTER REPEATED HEATING AT 1500°F. IN LEAD (TREATMENT IV L) SHOWING FINE CRACKS IN MATRIX. UNETCHED. X500.

Growth Above the Critical Temperature

19. The growth process in cast iron becomes more complicated when the heating temperature is raised from 1250° to 1500°F. Whether the heating at 1500°F. is conducted in lead or in air, consideration must be given to the possible cracking of the matrix due to the volume inversion which accompanies the eutectoid transformation. Also, on heating in air at 1500°F., appreciable oxida-

tion occurs, and the growth is decidedly affected thereby. However, oxidation is eliminated as a factor in the lead bath treatments, and the analysis of the growth becomes somewhat simplified.

20. Repeated heating in lead at 1500°F. produces much more growth than continuous heating for the equivalent length of time. Yet, there is only little difference in the extent of graphitization. Evidently, then, repeated heating and cooling through the critical temperature causes internal cracking, such as does not occur during repeated heating and cooling below the critical temperature. It seems that the cast iron is sufficiently strong to withstand the differential expansions and contractions at play during normal heating and cooling, but not the stresses set up by the volume changes attending the eutectoid transformation. The resulting cracks were observed microscopically, and are shown in Fig. 14. They are generally more numerous than the cracks which attend graphitization, but require similar care in polishing in order to reveal them without etching. Benedicks and Löfquist[10] have discussed this type of cracking in considerable detail, and Kikuta[5] has demonstrated conclusively by means of dilatometric runs in vacuo that cast iron undergoes a permanent increase in length on repeated heating and cooling through the critical range. The contraction usually accompanying the alpha-gamma transformation on heating is actually lessened by the formation of cracks, while the expansion normally accompanying the gamma-alpha transformation on cooling is enhanced by the formation of additional cracks. This results

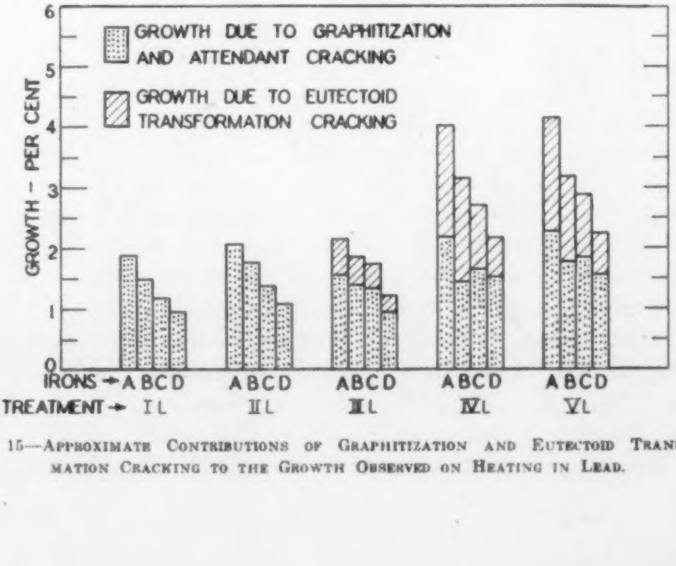


FIG. 15—APPROXIMATE CONTRIBUTIONS OF GRAPHITIZATION AND EUTECTOID TRANSFORMATION CRACKING TO THE GROWTH OBSERVED ON HEATING IN LEAD.

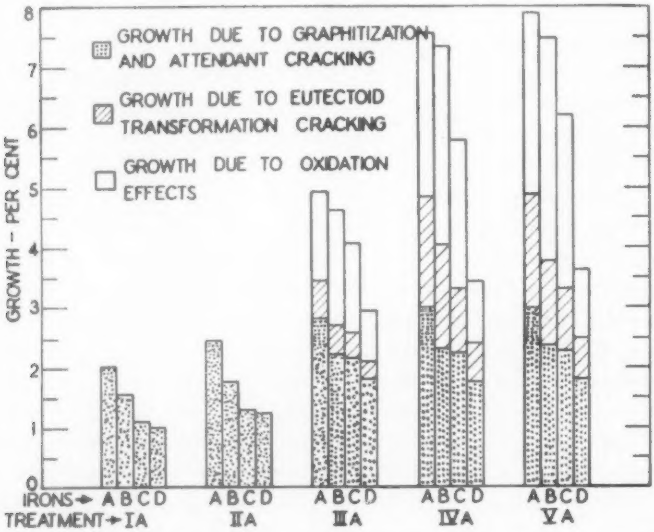


FIG. 16—APPROXIMATE CONTRIBUTIONS OF GRAPHITIZATION, EUTECTOID TRANSFORMATION CRACKING, AND OXIDATION TO THE GROWTH OBSERVED ON HEATING IN AIR.

in a net permanent increase in volume, and explains why repeated heating at 1500°F. and cyclic heating between 1500° and 1250°F. cause more growth than continuous heating at 1500°F.

21. The relative effects of eutectoid transformation cracking and of graphitization (with its attendant cracking) on the growth of the phosphorus irons during the five lead bath treatments are shown graphically in Fig. 15. As mentioned in the previous section, the growth at 1250°F. (treatments IL and IIL) is due essentially to graphitization and the attendant cracking. The growth due to this same cause in the 1500°F. treatments is computed from the growth per unit of carbon graphitized as given in Table 4 and the observed extent of graphitization reported in Table 3. The growth attributable to the eutectoid transformation cracking is taken as the difference between the measured overall growth and the calculated growth originating in the graphitization. Admittedly, this procedure is by no means rigorous, but at least it demonstrates the order of magnitude of the components contributing to the observed growth in the lead bath treatments.

22. According to Fig. 15, phosphorus retards the growth of cast iron on heating in lead above the critical temperature by decreasing the transformation cracking factor as well as the graphitization

factor. Here, just as below the critical temperature, it appears that phosphorus strengthens the matrix and increases the resistance to internal rupture when the eutectoid transformation and graphitization occur. This is in line with the findings of Bolton[11] whose load-elongation curves indicate that phosphorus improves the strength as well as the stiffness of cast iron at 1560°F.

23. On heating at 1500°F. in air, the growth values of all the irons are further increased by the occurrence of oxidation. The chemical analyses in Table 2 reveal a large loss of total carbon due to such oxidation. As illustrated in Fig. 12, the oxidation is not confined to the surface of the specimens, but extends well into the interior. Internal oxidation may contribute to the growth of cast iron in at least two ways: (1) the formation of voluminous oxide products, and (2) the internal bursting of the matrix around enclosed graphite pockets, due to high gas pressures resulting from gas-forming reactions. Such growth effects of oxidation are superimposed upon, and accentuated by, the previously mentioned growth factors which also operate during heating in lead at 1500°F., *i.e.*, permanent volume changes associated with graphitization and the eutectoid transformation.

24. The magnitudes of the three main contributions to the growth which takes place on heating in air are illustrated in Fig. 16. All of the growth occurring at 1250°F. is assigned to graphitization and attendant cracking. On heating above the critical temperature, the growth due to graphitization and attendant cracking is calculated from the extent of graphitization, as reported in Table 2, and the growth per unit of carbon graphitized, as given in Table 4. The additional growth due to eutectoid transformation cracking is assumed to be the same whether the heating is done in air or in lead, and this increment of growth has already been established for the lead treatments at 1500°F. in Fig. 15. The balance of the overall growth in the air heatings is attributable to oxidation effects.

25. From Fig. 16 it is evident that the growth associated with graphitization on heating at 1500°F. in air is about the same whether the heating is continuous or repeated. On the other hand, the growth increments due to the eutectoid transformation and to oxidation are considerably greater in the case of repeated heating than in continuous heating. Repeated heating through the critical range promotes cracking, and thus provides more channels for rapid oxygen penetration. Furthermore, the breathing action on alternate heating and cooling facilitates the innerward penetration

of oxygen and the outward escape of gaseous products of reaction. This explains the much greater carbon loss after repeated and cyclic heating at 1500°F. than after continuous heating.

26. Phosphorus retards the overall growth of cast iron on heating in air above the critical temperature, not only by reducing the graphitization and the eutectoid transformation factors, but also by reducing the oxidation effects. Kennedy and Oswald[3] and Sohnchen and Piwowarsky[4] have ascribed the oxidation resistance of phosphorus-rich irons to the obstruction which the steadite at the grain boundaries offers to the diffusion of oxygen. However, this explanation cannot be regarded as the main reason for the beneficial action of phosphorus. Phosphorus inhibits internal rupture by its strengthening effect, and thereby reduces the number of ready paths available for air penetration. In addition, phosphorus improves the inherent oxidation resistance of the matrix, just as in the case of steel[12]. The scale formed on the high phosphorus irons is thin and adherent, and probably offers appreciable protection against further oxidation. Such protection also applies to the exposed walls of cracks and graphite pockets, thus retarding the diffusion of oxygen through the matrix.

CONCLUSIONS

27. The growth of cast iron has been found to result from graphitization and attendant cracking, eutectoid transformation cracking, and oxidation effects. The relative magnitude of these growth factors has been roughly ascertained by conducting continuous and repeated heating tests below and above the critical temperature in air and in lead.

28. Phosphorus improves the growth-resistance of cast iron by inhibiting each of the above three causes of growth. However, chromium is more effective than phosphorus in retarding growth.

ACKNOWLEDGMENTS

29. The authors wish to acknowledge their indebtedness to Prof. P. E. Kyle, who supplied the cupola iron; to Dr. John Chipman, T. B. Winkler, and N. J. Grant, for making the cast irons; and to Dr. W. M. Saunders, Jr., and D. L. Guernsey, for their aid in the chemical analyses.

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The Detection of the Susceptibility of 18-8 Steel Castings to Intergranular Corrosion

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Abstract

This paper describes a rapid, simple, electrolytic test for detecting susceptibility of 18-8 stainless steels to intergranular corrosion. Heretofore susceptibility tests were time consuming and required a test section. The apparatus consists of a small lead cell which is clamped against the article to be tested and which contains a 60 per cent sulfuric acid solution containing 5 ml. per liter of Glycyrrhiza extract. The current may be supplied by a storage battery or a battery charging rectifier. The treatment takes 3 minutes and merely produces a small circular spot on the surface of the object being tested. The test spot on material susceptible to intergranular corrosion is characterized by a roughness at the grain boundaries. In most cases the naked eye can differentiate between susceptible and unsusceptible material. This test appears to be applicable to both wrought and cast materials. The effect of addition elements on susceptibility was studied. It was demonstrated that the test can be used to detect susceptibility to corrosion at points adjacent to welds. A comparison of this test with an electrical resistivity measurement test for susceptibility to corrosion was made.

1. The test to be described was developed to furnish a rapid, simple method for detecting susceptibility to intergranular corrosion in 18-8 stainless steels. It is known that this susceptible condition is associated with the precipitation of free carbides in the grain boundaries and is produced by heating the alloy in the temperature range 800° to 1600°F. as in welding, in improper annealing, or in service where such temperatures are met. A fairly com-

* Battelle Memorial Institute.

Note: This paper was presented by title at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

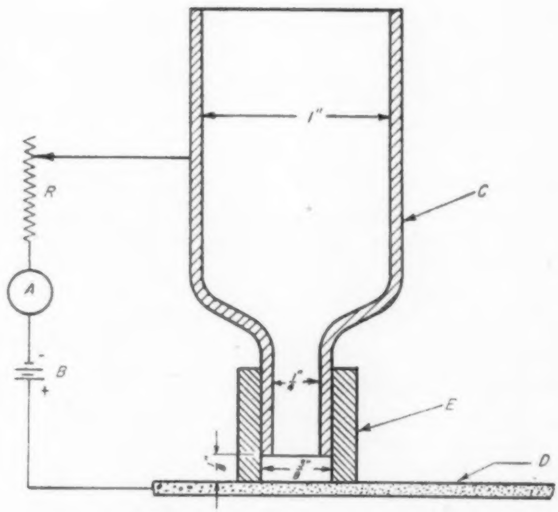

Fig. 1—Diagram of Cell and Electrical Circuit.

plete discussion of the cause and prevention of such a condition has been made by Bain and co-workers and by other investigators.[4-10*]

2. Present methods of detecting susceptibility cannot be carried out on a formed article because a sample section is required for examination and such a section cannot be obtained if the article is to be used later. One of these methods consists in subjecting a sample to corrosive conditions in some acid medium such as a mixture of copper sulfate and sulfuric acid. Such tests require at least 72 hours to run. Another method used is to make a metallographic examination for carbides at the grain boundaries.[11, 12] Such a study is time consuming and also requires test sections.

3. The test described here can be carried out on a completed structure and requires only a few minutes to run. A small portion of the piece under test is given an electrolytic treatment and the appearance of the resulting spot tells whether the steel is susceptible to intergranular attack or not. That is, a piece which is immune from attack shows a fairly uniform polish while a susceptible piece shows attack at the grain boundaries. When the examination is made under oblique illumination the test spot on a piece of immune wrought material will appear black due to the high reflec-

* Superior numbers refer to corresponding references at end of the paper.

tivity of the smooth polish obtained on this type material. The test spot on a piece of immune cast material will appear less black due to the ridges formed by dendrites. Wrought and cast material which is susceptible will show white at the grain boundaries due to diffuse scattering of light at the rough edges. In wrought material the test spot on a sensitized piece will appear frosty due to the fine grain size; in large grained cast material the test spot will appear fairly dark with the grain boundaries outlined in white.

EXPERIMENTAL METHOD

4. The small test spot mentioned is produced by an anodic treatment with a cell that can be clamped onto a sample or an actual structure. The apparatus can thus be made into a shop tool.

5. The cell and electrical circuit used are illustrated in Fig. 1. The cell *C* is lead, joined to the steel plate *D* and insulated from it by a short piece of rubber tubing *E*. The cell is forced tightly against the steel plate by some clamping mechanism. The seal formed by the rubber against the steel plate is sufficient to retain the liquid bath inside the cell. The spot treated can be made any shape desired, depending on the shape of the rubber gasket. The spot is not deep and could be used for identification purposes. The cell illustrated polishes a circular spot about $\frac{3}{8}$-in. in diameter.

6. The bath consists of 60 per cent (by weight) sulphuric acid to which is added 5 ml. per liter of Glycyrrhiza extract (U.S.P.). This cell requires about 2 to 2.5 ml. of the bath which is discarded after each test.

7. Power may be supplied by a storage battery or a battery charging rectifier. Fig. 1 illustrates the use of a battery, the current being controlled by the resistance R. The recommended current density is about 14 amperes per sq. in. which for the cell described requires 1.5 amperes at about 5 to 6.5 volts. The time used is three minutes. When the cell is operated at 1.5 amperes the initial voltage is usually 7.4 and the voltage gradually falls to about 5.0. This is due to the lowering of the resistance in the cell as the bath heats. This resistance drop is equalized by increasing resistance R, so that a constant current flows.

8. The temperature effect is not serious unless the test is being applied to large objects, when the mass of metal is so great that the heat generated in the cell is dissipated so rapidly that an even test

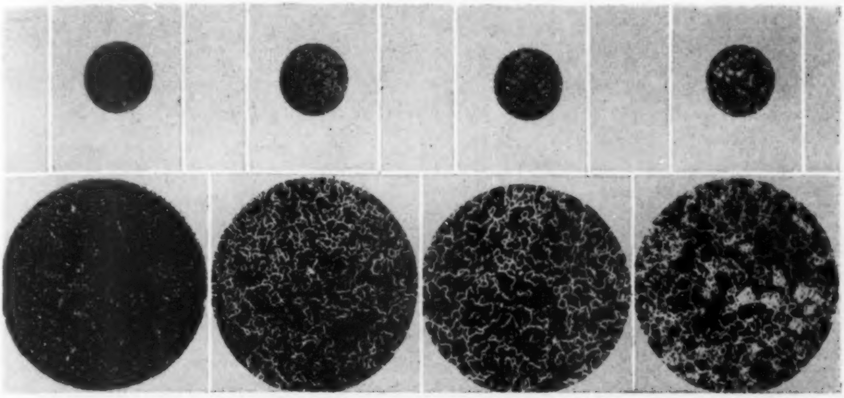

FIG. 2—PHOTOGRAPHS AT ACTUAL SIZE (ABOVE) AND x3 (BELOW) OF CAST 18-8 SAMPLES HEAT TREATED AS INDICATED AND SUBJECTED TO THE ELECTROLYTIC TEST. THE ANALYSIS OF THE STEEL IS: 0.04 C, 19.48 CR, 8.96 NI, 0.76 MN, 1.09 SI, 0.10 CU, 0.021 S AND 0.016 PER CENT P.

1	2	3	4
QUENCH-ANNEALED	30 MIN. 1200°F.	4 HRS. 1200°F.	72 HRS. 1200°F.

spot is not produced. One simple method to overcome this is to heat the object to be treated by running hot water over it until it reaches 120-140°F. In this manner the heat drain on the cell is lessened and a satisfactory surface will result. Another method is to contruct the cell with more than ⅛-in. between the lead and the sample, and thus generate more heat in the bath due to increased resistance. A third method is to increase the current density. This method must be used with care because there is the possibility of polishing sensitized material if too much current is used. A little experimentation will indicate the best condition to use for an object of a particular size. All tests to be described later were made under the same conditions.

9. In most cases the presence of susceptibility to intergranular corrosion can be detected as a frostiness and grain boundary attack, which is readily noticeable. Partial sensitization sometimes requires more careful examination, such as viewing at various angles or the use of a magnifying lens.

10. Most rolled or machined surfaces can be tested without any surface preparation except removal of grease or dirt. Cast surfaces, which usually are rough, are prepared by grinding a small flat spot and then polishing with a series of emery papers to provide a fairly smooth surface. It is not necessary to remove all scratches.

CAST STEELS TESTED

Progressive Sensitization

11. Samples of cast 18-8 steel of 0.04 per cent carbon content were sensitized by heating at 1200°F. for 30 minutes, four hours, and 72 hours. Visual examination after the electrolytic treatment showed a definite increase in light, rough area corresponding to the time of sensitization; that is, samples that had been held at 1200°F. for the longest periods of time showed the most extensive light areas. Fig. 2 includes photographs of some of these test spots at actual size and at three diameters, which reproduce fairly well the appearance of the spots when the sample is viewed obliquely. The heat treatment given the sample is noted below the corresponding photograph and the chemical analysis of the steel used is included. The spot on the first sample, which was quench-annealed, appears uniformly dark and rough. The unevenness in surface is characteristic of cast materials and is caused by the dendritic formations present. Wrought material which does not have this structure shows a uniformly black spot indicating a very even, smooth surface. Sensitized material does not give a uniform over-all finish but is rough at the grain boundaries. This is illustrated by the second sample, sensitized for 30 minutes at 1200°F., which shows the grain boundaries outlined in white. This effect is produced by the scattering of the light at all angles at the rough areas which have been selectively etched adjacent to the points of carbide precipitation; that is, the grain boundaries. The faces of the grains have been polished fairly smoothly (limited by dendrites) and appear as dark areas. It is evident that the extent of carbide precipitation has increased with the time of heating at 1200°F. because sample 4 shows a much more complete outline of grain boundaries than 2 and 3. Sample 4 also indicates the formation of carbides within the grain, as shown by the white spots.

12. Other tests on the same material indicate that sensitization can be produced after only a few minutes of heating at 1200°F. Other tests indicate that sensitization is produced more rapidly in large-grained material than in fine-grained.

Higher Carbon

13. Cast samples of 18-8 steel containing 0.067, 0.10, 0.125, and 0.16 per cent carbon were treated for 4 hours at 1200°F., and in all cases a differentiation could be shown between the sensitized and unsensitized material by means of the electrolytic test. Fig. 3 illus-

trates sensitized and unsensitized samples of 18-8 of 0.10 and 0.16 per cent carbon. The pictures illustrate that the distinguishing marking of sensitization is the outline of grain boundaries. Such a pattern is very different from that seen on the pieces that were quench-annealed. The patterns in these cases are due to the dendritic structure characteristic of cast materials.

Wrought Materials

14. Tests similar to those described above have been made on wrought 18-8 steels of various carbon content. The tests can be used

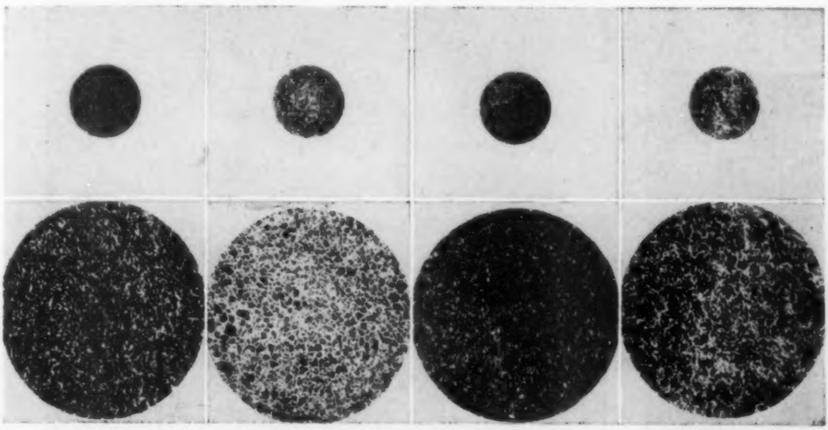

FIG. 3—PHOTOGRAPHS AT ACTUAL SIZE (ABOVE) AND x3 (BELOW) OF CAST 18-8 SAMPLES OF 0.10 PER CENT AND 0.16 PER CENT C. HEAT TREATED AS INDICATED AND TESTED FOR SENSITIZATION.

0.16 PER CENT		0.10 PER CENT	
QUENCH-ANNEALED	4 HRS. 1200°F.	QUENCH-ANNEALED	4 HRS. 1200°F.

to follow progressive sensitization and the effect of sensitizing temperature. Test indicated that the addition of columbium to the steel removed the susceptibility to intergranular corrosion.

Welds

15. Fig. 4 includes photographs at actual size and at 3 diameters of 1-in. round steel sawed lengthwise, quench-annealed at 2100°F., welded together end to end, and then tested for sensitization at various points. The steel is 18-8 of 0.125 per cent carbon and the welding rod used was 18-8 of 0.07 per cent carbon. The photograph shows the sensitization produced adjacent to a weld. The photograph at 3 diameters is marked so that the areas of special interest can be noted. The line of demarcation between weld metal and

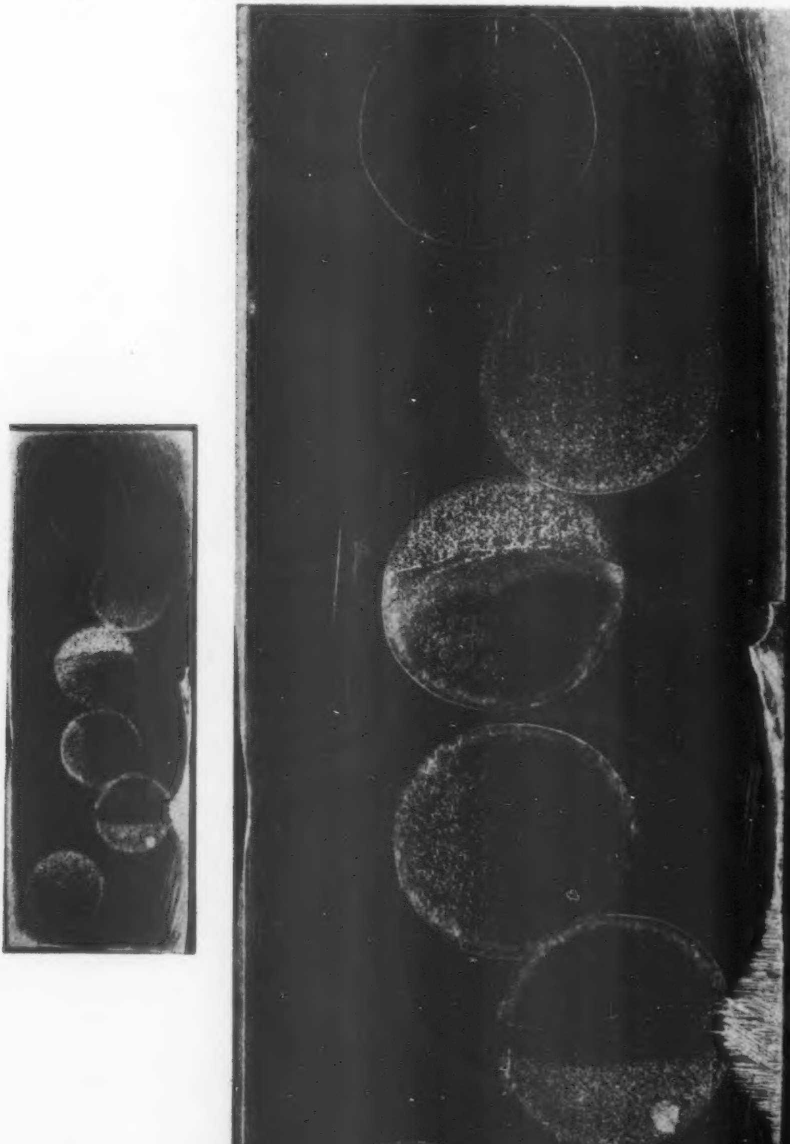

FIG. 4—PHOTOGRAPHS OF WELDED SECTIONS OF 18-8 STEEL OF 0.125 PER CENT C.—ACTUAL SIZE ABOVE—x3 BELOW.

SENSITIZED AREA AREA NOT SENSITIZED WELD METAL SENSITIZED AREA AREA NOT SENSITIZED BY WELDING

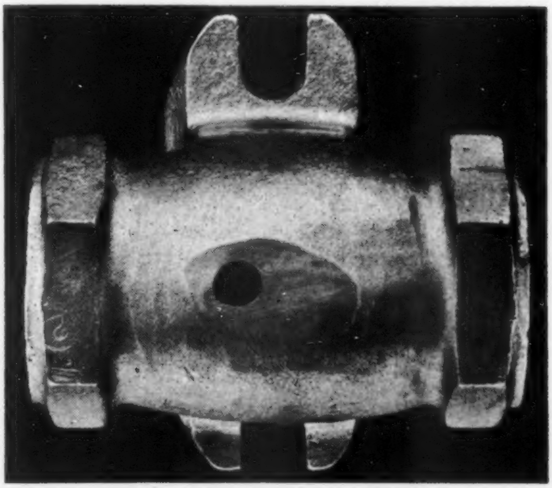

FIG. 5—PHOTOGRAPH OF TEST SPOT ON AN 18-8 STAINLESS STEEL CAST VALVE BODY. THE SMOOTH POLISH AS SHOWN BY THE BLACK SPOT INDICATES FREEDOM FROM SENSITIZATION.

adjacent steel is evident. On side *A* the sensitized zone in the steel is adjacent to the weld while on side *B* there is a narrow portion beside the weld that is not sensitized. The probable explanation for this area is that the steel was heated above the sensitizing range at this point and cooled rapidly enough so that no carbide precipitation resulted. Note also the extent of the sensitized zone. It is about $^3/_8$-in. wide and beyond it the steel is in good condition, as is evidenced by the smooth polish observed on the third spot on side *A*. The white lines in this spot are due to grinding scratches only and cannot be mistaken for grain boundaries or sensitized areas. Also, a certain area in the weld shows sensitization. This was probably produced at the spot in the weld that was held in the sensitization range for the longest time.

16. A welded sample identical with that in Fig. 4 was quench-annealed at 2100°F. after being welded and was then tested for sensitization. The test showed no sensitization at any place and indicates that the susceptibility to intergranular corrosion can be removed by proper annealing.

17. Two pieces of cast 18-8 steel of 0.10 per cent carbon were welded together and tested for sensitization at various points. Sensitized areas were found on each side of the weld in about the same location as those shown on side *B* in Fig. 4.

Testing of Castings

18. Fig. 5 illustrates a stainless steel valve body that was tested by the method described. The dark test spot free from grain boundary lines indicates to the prospective user that the casting is free from carbide precipitation.

Effect of Molybdenum Addition

19. Cast samples of 18-8 steel containing 3 per cent Mo. with 0.04 and 0.10 per cent carbon were tested. The samples that were water quenched from 2100°F. gave a fairly smooth polish, although not as bright as that for ordinary 18-8. Samples containing 0.04 per cent carbon and sensitized for two hours at 1200°F. showed very little carbide precipitation, while samples containing 0.10 per cent carbon showed an extensive degree of precipitation after the same treatment.

Effect of Titanium Addition

20. Cast samples of 18-8 steels containing 0.60 per cent Ti. as a stabilizer were tested after quench-annealing and after sensitizing at 1300°F. for three hours. In both cases a rough polish resulted. Fig. 6 illustrates the appearance of the spots. Neither one shows dark grains outlined by white boundaries. A microscopic

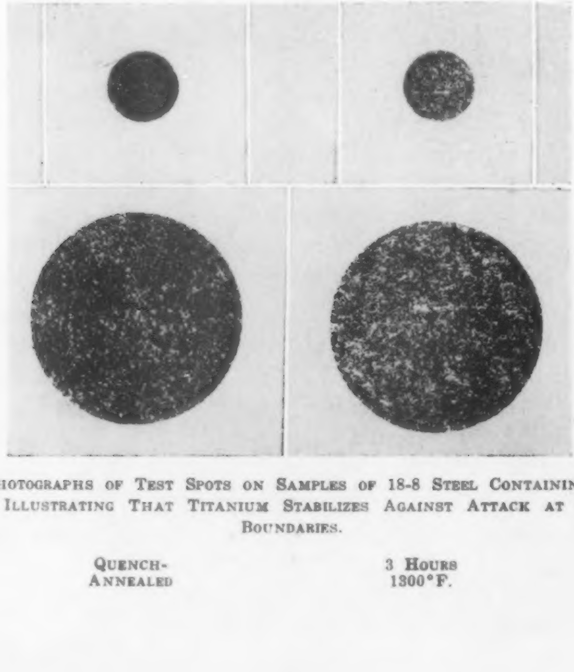

FIG. 6—PHOTOGRAPHS OF TEST SPOTS ON SAMPLES OF 18-8 STEEL CONTAINING 0.60 PER CENT TI, ILLUSTRATING THAT TITANIUM STABILIZES AGAINST ATTACK AT THE GRAIN BOUNDARIES.

QUENCH-ANNEALED | 3 HOURS 1300°F.

examination of these spots also shows the structure to be different from any found in the other steels. Also in the titanium steel samples the grains themselves seem to be etched and appear dark and rough. The grains in the sample that was sensitized at 1300°F. seem to be rougher than those in the quenched sample. The probable explanation for this result is that the titanium has formed carbides and the electrolytic test is picking out these carbides which are present in both samples. However, the test does not indicate grain boundary attack and therefore predicts that the steel is stable and not susceptible to intergranular attack.

21. Samples of the same steel were given a stabilizing treatment by heating for 2½ hours at 1560°F. One piece was then heated at 1200°F. for 2 hours. This piece and a stabilized one were tested and both showed spots similar to those illustrated in Fig. 6. Apparently titanium stabilizes by forming carbides and the test detects the presence of carbides and shows them to be in the grain rather than at the boundary.

Correlation with Corrosion Tests

22. Various methods of measuring the degree of sensitization have been employed, such as magnetic measurements, the measurement of electrical resistivity, or the measurement of the degree of cracking produced on bending over a mandrel. Resistivity measurements will be described.

23. Measurements of electrical resistivity have been made on samples before and after subjection to acid copper sulfate attack. An increase in resistivity indicates grain boundary attack. These results are compared with those obtained by the test spot method taken before the sample was subjected to the acid corrosion.

24. Table 1 gives a comparison of the results of these tests. Column 1 includes the type steel, column 3 the heat treatment, column 4 the percentage change in electrical resistance after subjection to acid copper sulfate for 140 hours in one series and 163 hours in the other, column 5 lists the results of the electrolytic test. In the first series this test was made after only two hours of sensitization instead of after 100 hours as for the resistance measurements, while in the other series the spot test was made either after the sample was quench-annealed or after 100 hours at 1200°F.

25. The sulfate solution used was made up of 13 grams per liter of $CuSO_4 \cdot 5H_2O$ and 47 ml. per liter of H_2SO_4 (1.84 S.G.). The sample dimensions were 4½ by ¼ by ⅛-in.

Table 1

COMPARISON OF SUSCEPTIBILITY TESTS ON CAST MATERIALS

Steel	*Carbon %*	*Treatment*	*Percentage Change in Electrical Resistance 140 hrs. in acid $CuSO_4$*	*Result of Electrolytic Test 2 hrs. sensitization*
19-9 + Bi	0.19	100 hr. 1200°F.	284	Susceptible
19-9 + Bi	0.26	100 hr. 1200°F.	157	Sl. Susceptible
19.9 + Bi	0.20	100 hr. 1200°F.	15.6	Sl. Susceptible
19-9	0.15	100 hr. 1200°F.	1860	Susceptible
19-9 + Bi	0.15	100 hr. 1200°F.	915	Susceptible
19-9	0.25	100 hr. 1200°F.	360	Susceptible
19-9 + Bi	0.25	100 hr. 1200°F.	478	Susceptible
19-9	0.14	100 hr. 1200°F.	292	Susceptible
19-9 + Bi	0.14	100 hr. 1200°F.	65	Very Sl. Susceptible
			163 hrs. in acid $CuSO_4$	*Quench-annealed or 100 hrs. sensitization*
19-9	0.10	Quench-Annealed	0	Immune
19-9	0.10	100 hr. 1200°F.	22,100	Susceptible
19-9 + Cb	0.10	Quench-Annealed	0	Immune
19-9 + Cb	0.10	100 hr. 1200°F.	0	Immune
19-9 + Ti	0.10	Quench-Annealed	0	Immune
19-9 + Ti	0.10	100 hr. 1200°F.	0	Immune
19-9 + Mo	0.10	Quench-Annealed	0	Immune
19-9 + Mo	0.10	100 hr. 1200°F.	0	Immune
19-9 + Bi	0.10	Quench-Annealed	0	Immune
19-9 + Bi	0.10	100 hr. 1200°F.	110	Susceptible

26. The results in the table show that the electrolytic test predicted susceptibility to corrosion in all cases that later showed intergranular attack in the acid copper sulfate. It was found that it was necessary to examine some of the spots under magnification to be absolutely certain of susceptibility. Examination of the sample held obliquely is valuable in detecting the grain boundary attack. It is felt that in general the test should prove valuable if proper care is used in examining the test spot.

SUMMARY

27. A rapid electrolytic test has been developed for the detection of carbide precipitation in 18-8 steels. When the test is applied under proper conditions, and the spot produced is viewed by oblique illumination, the appearance of dark grains outlined by light boundaries indicates susceptibility of intergranular attack. The formation of a uniform test spot indicates the lack of such susceptibility; and a spot that shows attack at areas other than the grain boundaries indicates carbide precipitation that may occur in a harmless form.

28. The cell used is an open, lead tube, one end of which is sealed to the surface under test by means of rubber tubing slipped over the lead. The bath consists of 60 per cent sulfuric acid, to which

is added 5 ml. per liter of Glycyrrhiza extract. A test spot about $\frac{3}{8}$-in. in diameter requires 1.5 amperes at about 5 to 7 volts. The treatment takes three minutes. Very little surface preparation prior to testing is necessary.

29. The test appears to be applicable to both wrought and cast materials of various carbon contents. The effect of time and temperature on the degree of carbide precipitation produced can be followed by the test.

30. It has been demonstrated that the test can be used to detect susceptibility to corrosion at points adjacent to welds.

31. The effect of addition elements on sensitization has been studied.

32. Photographs illustrating many of the above effects demonstrate that the naked eye is usually sufficient to differentiate between sensitized and unsensitized material that has been subjected to the test procedure.

33. The test is nondestructive and can be applied to completed structures.

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Direct Determination of Combined Carbon in Cast Iron and Steel

By J. G. Donaldson*, Columbus, Ohio

Abstract

A rapid and accurate method for determining combined carbon in cast iron and steel is described. The results were found to be in better agreement in precision and accuracy than those obtained by present methods of analysis, and with considerable saving in time. The method here described requires only 15 min. per determination. The method is not applicable to chromium steels nor any other alloy steels not soluble in the acid mixture used. The apparatus is conveniently subdivided into small independent units for added flexibility.

1. In the organization with which the author is connected, frequent requests are received for the combined carbon content of cast iron, as knowledge of the proportion of carbon as graphite and as combined carbon, or cementite, is of value in studying metallurgical practice.

2. The present accepted method of determining combined carbon consists of the determination of total carbon and graphite carbon, the combined carbon being the difference between those values. This method has the disadvantage of requiring hours rather than minutes to perform, and the entire burden of error is thrown on the combined carbon figure. This procedure gives erratic results, as may be verified from figures given in the U. S. Bureau of Standards certificates, the results of which are given in Tables 1 and 2.

3. The direct method herein outlined has the advantage over the present method in speed and accuracy, as each determination can be completed in 15 min. and with good precision.

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Note: This paper was presented by title at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

Table 1

BUREAU OF STANDARDS CAST IRON SAMPLES

B. of S. Sample No.	Combined Carbon, per cent — Bureau of Standards Certificate Results: Maximum	Minimum	Recommended Value	B. M. I. Method
122	0.78	0.70	0.74	**0.70**
122	0.78	0.70	0.74	**0.76**
6d	0.77	0.61	0.66	**0.67**
6d	0.77	0.61	0.66	**0.68**
7c	0.48	0.40	0.44	**0.42**
7c	0.48	0.40	0.44	**0.43**
4e	0.52	0.43	0.48	**0.47**
4e	0.52	0.43	0.48	**0.47**

4. The method consists of solution of the sample in a dilute nitric-sulphuric-phosphoric acid mixture, containing a small amount of silver nitrate as a catalyst. Oxidation of the combined carbon is accomplished by boiling with a hot solution of ammonium persulfate, and passing the evolved carbonaceous gases through heated copper oxide. After removal of sulphur gases and water, the evolved carbon dioxide is absorbed in ascarite and weighed.

5. The procedure is carried out in a closed system to prevent escape of any organic gases evolved in dissolving the sample.

EXPERIMENTAL WORK

6. It has been shown by J. H. Whiteley[1] that when steel samples are boiled at 100°C. for 10 min. in dilute nitric acid (1.2 sp. gr.), from 25 to 30 per cent of the carbon present is evolved as CO_2, CO, HCN and hydrocarbons. This clearly points to a closed system for the determination, as all gases evolved during solution of the sample must be conserved and oxidized. The carbon still retained in the solution must be oxidized with ammonium persulfate to carbonaceous gases, which are boiled out of the solution and further oxidized by the heated copper oxide to CO_2, the ultimate oxidation product.

7. A dilute solution of nitric-sulphuric-phosphoric acid, containing a small amount of silver nitrate as a catalyst, was found most suitable for the determination. For the first tests, a sample of white iron, which had been previously analyzed, was used. This was selected because of its high combined carbon content, much

[1] Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. VIII, 1917.

higher than normally found. When this could be determined with consistently precise and quantitative results, the experiment was continued to cover the available Bureau of Standards samples of cast iron and also several Bureau of Standards samples of steel. In the latter case, the carbon recovered represented the total carbon present in the steel. Some steel samples containing small amounts of alloying elements were tried with good results, except in the case of chromium steel. One per cent chromium in the steel was found to defeat the determination, as the metal was not completely dissolved in the acid, and the results were low.

Apparatus

8. The apparatus (Fig. 1) consists of a 250 ml.* flask (*A*) with standard taper neck. A 125 ml. funnel (*B*) extends down through the ground glass stopper to ½-in. or 12 mm. from the bottom of the flask (*A*). A coil condenser (*C*) is welded to the stopper and extends over and down into a 250 ml. gas washing bottle (*D*) containing 150 ml. of a saturated aqueous solution of chromic acid. The outlet from the gas washer is attached to a glass tube (*E*) filled with copper oxide and extending upward into an electric coil heater (*F*).

9. After the copper oxide tube, the apparatus consists of: a Fleming washer (*G*) containing 35 ml. of sulphuric acid saturated with chromic acid; a second Fleming washer, empty to remove spray, a Stetser-Norton absorption bulb (*J*) charged with barium perchlorate drying agent; and a second Stetser-Norton absorption

Table 2

Bureau of Standards Steel Samples

B. of S. Sample No.	*Combined Carbon, per cent* — *Bureau of Standards Certificate Results* — *Maximum*	*Minimum*	*Recommended Value*		*B. M. I. Method*
16c	1.02	1.00	1.01		0.97
16c	1.02	1.00	1.01		1.01
20d	Provisional Certificate		0.411		0.430
20d	Provisional Certificate		0.411		0.434
9c	0.206	0.198	0.202		0.202
9c	0.206	0.198	0.202		0.206
130	0.460	0.448	0.454	(Pb steel)	0.480
30c	0.503	0.481	0.489	(Cr-V steel)	0.306**
111	0.207	0.196	0.202	(Mo-Ni steel)	0.213

* Milliliter.
** Chromium steel not soluble in the acid mixture used.

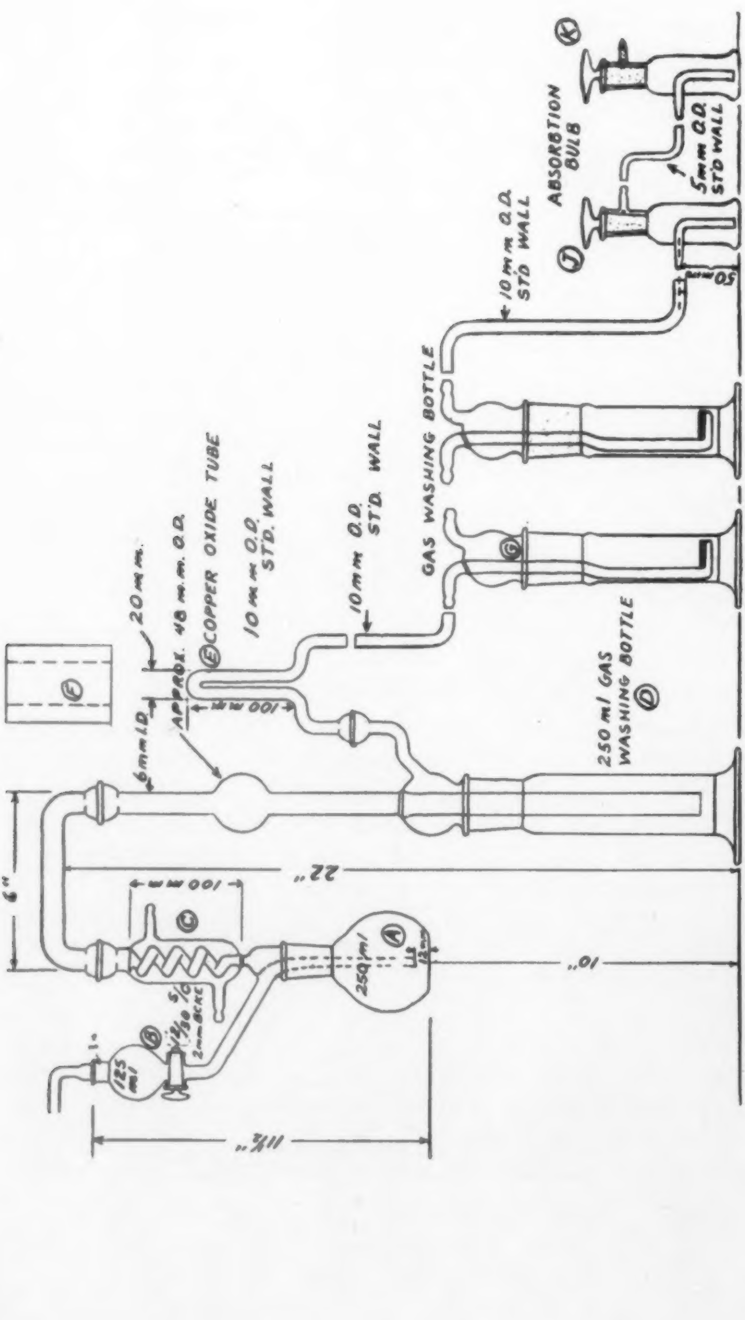

FIG. 1—APPARATUS USED IN THE DIRECT DETERMINATION OF COMBINED CARBON IN CAST IRON AND STEEL.

Table 3

ROUTINE LABORATORY CAST IRON SAMPLES

Sample No.	Combined Carbon, per cent — Recorded Value*	Combined Carbon, per cent — B. M. I. Method
A	0.41	0.40
B	0.37	0.37
C	0.08	0.08
D	0.38	0.38
E	0.47	0.47
F	0.44	0.49
G	0.48	0.49
H	0.25	0.27
I	0.66	0.61
J	0.44	0.45
K	0.20	0.21
L	0.20	0.20

bulb (*K*) charged with ascarite to collect the CO_2, which is measured gravimetrically.

10. All glass construction is necessary until after the copper oxide tube, because gum rubber connections are immediately attacked by nascent oxygen giving a non-reproducible blank. Rubber connections, however, may be used after the copper oxide tube.

PROCEDURE

11. Weigh 2.727 grams of sample into flask (*A*). Heat the copper oxide tube to 300-310°C. and pass oxygen through the train at a rate of about 250 ml. per min. for a few minutes. Close stopcock between funnel (*B*) and flask and attach a weighed ascarite bulb to the train.

12. Remove the oxygen line and pour 40 ml. of dissolving acid into the funnel. This dissolving acid consists of 5.25 grams of silver nitrate ($Ag\ NO_3$), 1800 ml. of water, 500 ml. nitric acid (HNO_3), 160 ml. sulphuric acid (H_2SO_4) and 200 ml. phosphoric acid (H_3PO_4).

13. Force the acid into the flask under pressure by reconnecting oxygen supply and opening stopcock. When the first violent action has subsided, place a low flame under the flask and boil gently until sample dissolves and nitrous gases disappear.

14. Remove flame and disconnect oxygen supply. Dissolve 5 grams of ammonium persulfate in 100 ml. of boiling water and pour

* In Tables 3 and 4, the "recorded value" is that previously obtained by difference, total carbon-graphitic carbon, during routine analysis of the samples.

into the funnel (B). Open stopcock and force into the flask by reattaching the oxygen supply.

15. Boil the solution for 4 min., then remove flame. Sweep out the system with oxygen for another 4 min., remove ascarite bulb and weigh. The increase in weight represents the combined carbon as CO_2.

RESULTS

16. Tables 1, 2, 3 and 4 show the results obtained by the presently accepted and the new methods. Table 1 shows the results obtained on Bureau of Standards certificated samples of cast iron and Table 2 shows the results obtained on similar samples of steel. Table 3 shows the results obtained on routine laboratory samples while Table 4 shows a comparison of the results obtained by the two methods by an independent operator.

17. In Tables 3 and 4, the "recorded value" is that previously obtained by difference, total carbon-graphitic carbon, during routine analysis of samples.

Table 4

UNKNOWN SAMPLES DETERMINED BY AN INDEPENDENT OPERATOR

	Combined Carbon, per cent	
Sample No.	*Recorded Value**	*B. M. I. Method*
M	0.34	0.33
N	0.38	0.39
O	0.48	0.46
P	0.44	0.43
R	0.74	0.76
S	0.25	0.26
T	0.23	0.25

ACKNOWLEDGMENT

18. The author wishes to acknowledge the permission of Battelle Memorial Institute, which financed the investigation, to publish the results. Acknowledgment is also made of the generous advice and assistance of John D. Sullivan and other members of the Institute staff.

* In Tables 3 and 4, the "recorded value" is that previously obtained by difference, total carbon-graphitic carbon, during routine analysis of the samples.

The Drying Out of Synthetic Sands

By N. J. Dunbeck*, Eifort, Ohio

Abstract

Since the drying-out qualities of a molding sand are important in foundry molds, the author has made a study of this characteristic in both naturally-bonded and synthetic sands. His approach to the solution of the drying-out problem is through the introduction into the sand mixture, by way of the tempering water, of treating agents designed to lower the vapor pressure of the water. The test results in this paper include various treatments of southern and western-bentonite-bonded sands and fireclay-bonded sands. A large number of substances which lower the vapor pressure of water were added to the sand mixtures in the manner indicated above. The paper records not only the effect of these various agents on the drying-out characteristics of sand mixtures, but also their effect on the properties of the sand. Since fuel oil has been used to reduce the drying-out of molding sand, the effect of this material on molding sands also was investigated.

1. Synthetic sands are those made in a foundry, as required, from materials so selected by the foundryman as to best fit his particular needs.

2. The silt and fines in naturally-bonded sands have a large surface area and require a substantial amount of tempering water to wet the surface and make them moldable. The clay in naturally-bonded sands is usually less efficient than specially-selected bond clays and a relatively large amount of tempering water is necessary to wet and make plastic this substantial amount of clay.

3. In contrast, synthetic sands contain a small amount of strong

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Note: This paper was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

clay and a minimum amount of fines. Less tempering water is required and a higher permeability results. Tempering water seems to be evaporated faster from such an open sand and it is believed that the loss is more apparent and more of a problem due to the small amount of water present. For example, if a synthetic sand containing 4 per cent water and naturally-bonded sand containing 7 per cent water each lose one per cent water by evaporation on a hot day, the synthetic sand loss is one-quarter while the naturally-bonded sand loss is only one-seventh.

CURRENT REMEDIES

4. In present practice, synthetic sand is tempered heavier on hot days and allowance thus is made for the probable evaporation before use. The wide use of synthetic sand is evidence that this is a satisfactory method of producing castings, but it would be very desirable to reduce the moisture loss in both naturally-bonded and synthetic sands.

5. Glycerine has been successfully used but is expensive. Fuel or crude oil is also in use. Usual addition of such oils is about one gallon per ton of sand, the oil being added only a short time before the mixer is dumped. Oil also may be dripped slowly onto a system sand on a conveyor belt before it reaches a mixer of any type.

6. Use of fuel oil in this manner, in a large malleable foundry, not only has eliminated previous complaints from the molders but has permitted an actual reduction of 0.75 per cent in tempering water added, with satisfactory "feel" of the sand maintained. It is claimed that the oil has a slight lubricating effect on the pattern and that less sticking of hot sand and less cleaning of pattern is required. It also has permitted a substantial reduction in the amount of sea coal used. Presumably the fuel oil gives off a gas with similar action to that evolved from sea coal.

7. The use of fuel oil ordinarily would be expected to result in somewhat lower strength. Within the normal moisture range, synthetic sands become stronger as moisture is decreased. In the particular case mentioned, the reduction in moisture content more than compensated for any strength loss due to the oil addition. In other foundries, the addition of oil is said to have required the use of more bond clay.

8. The one and principal objection to the use of fuel oil is the annoying smoke which is created on pouring. This is of sufficient nuisance that it almost prohibits the use of oil in floor shops. The smoke is of no consequence when the castings cool on a covered mold conveyor.

EXPERIMENTAL WORK

9. Any steps toward the solution of the problem of drying out of synthetic sands were of evident value, so work on the matter was included in a research project sponsored at Battelle Memorial Institute, Columbus, Ohio, by the company with which the writer is associated. In this project, it was decided to measure the effect of chemical and physical agents which lower the vapor pressure of water. Such agents might be expected to give the maximum reduction in the drying rate of synthetic sands.

10. Since temperature and humidity have a great effect upon the rate of drying-out, all mixing and testing was performed in a room which was maintained at 77°F. and 55 per cent humidity. Unless otherwise indicated, all treating agents were added in solution in the tempering water. All additions were by percentage of the weight of clay in the mixture. All testing was done in accordance with A. F. A. standards. Ten specimens of each sand were weighed immediately after mixing and exposed on an enameled plate. All surfaces except the bottom were exposed. The drying of such a specimen would be more rapid than sand in a heap or facing box. The test can be considered, therefore, to be an accelerated one but comparable from one mixture to another. The samples were reweighed at intervals and the loss expressed as the percentage of the original moisture content which was lost during drying.

Effect of Agents Used on Bentonite and Fire-Clay-Bonded Sands

11. Table 1 shows that some materials were effective in reducing the drying-out of southern-bentonite-bonded sand during short periods. If our problem was the drying-out of facing sands, it seems likely that agents should be selected which offered the greatest decrease in drying-out over short periods of time. Among the most effective of these were lithium chloride, zinc chloride, ethylene glycol and dextrin. If our problem was the drying out of system or heap sand, lithium chloride is indicated as the most effective over long periods of time.

Table 1

EFFECT OF VARIOUS AGENTS ON SOUTHERN-BENTONITE-BONDED SAND

Agent Added	*Per Cent Added*	*Moisture Loss, Per Cent* — *Time, min.* 30	60	90	120	180	360
None (blank)	—	6.1	10.0	13.9	16.6	22.1	31.9
Lithium Chloride	0.5	6.3	9.7	13.6	16.3	21.9	31.6
	2.0	5.5	9.2	11.2	15.2	19.6	27.8
	5.0	5.0	8.6	11.2	13.6	17.5	24.0
Potassium Acetate	0.5	5.6	9.6	12.7	15.5	20.6	29.1
	2.0	5.9	10.2	13.3	15.9	20.7	29.2
	5.0	5.8	9.4	12.4	15.2	19.9	28.2
Zinc Chloride	2.0	5.7	8.8	10.8	13.4	16.2	31.0
	5.0	5.3	8.8	11.2	12.8	16.5	31.0
Cereal Binder No. 1	2.0	5.9	8.7	11.5	11.5	18.3	33.0
	5.0	6.0	10.0	11.4	12.3	18.1	33.2
Ethylene Glycol	5.0	5.4	9.5	12.9	16.6	20.0	32.7
Sulphuric Acid	5.0	4.5	8.7	12.0	15.1	19.9	33.4
Phosphoric Acid	5.0	4.7	8.3	10.7	14.1	17.9	28.9
Dextrin*	5.0	4.2	8.8	11.9	15.0	19.9	31.5

12. Table 2 shows that most treating agents were more effective on fire-clay-bonded sands than on southern-bentonite-bonded sands,

Table 2

EFFECT OF VARIOUS AGENTS ON FIRE-CLAY-BONDED SAND

Agent Added	*Per Cent Added*	*Moisture Loss, Per Cent* — *Time, min.* 30	60	90	120	180	360
None (blank)	—	6.5	11.0	14.7	18.3	24.4	41.0
Lithium Chloride	2.0	5.4	8.5	11.3	13.5	17.8	29.9
	5.0	3.1	5.3	7.1	8.8	11.2	17.9
Potassium Acetate	2.0	4.8	8.3	11.4	14.1	18.7	31.2
	5.0	4.9	8.0	10.2	12.1	15.4	26.0
Zinc Chloride	2.0	4.5	7.9	10.1	12.7	18.0	31.2
	5.0	4.2	7.2	9.2	—	15.7	26.6
Cereal Binder No. 1**	2.0	4.3	7.9	10.3	13.0	18.1	27.0
	5.0	4.1	7.4	9.7	11.9	15.6	25.2
Ethylene Glycol	5.0	4.5	7.8	10.3	12.9	17.0	28.5
Sulphuric Acid	5.0	5.2	9.0	12.3	14.7	18.7	30.8
Phosphoric Acid	5.0	5.8	8.5	11.4	13.9	18.5	31.4
Dextrin**	5.0	5.2	7.6	10.5	13.0	17.3	29.1

* Added dry to the clay sand mixture.
** Added dry to the clay sand mixture.

which leads to the belief that different treating agents should be used, dependent on the type of bond in use. Lithium chloride, zinc chloride, cereal binder No. 1 and ethylene glycol were most effective, lithium chloride being the most effective. This was particularly true over long drying periods.

Table 3

EFFECT OF VARIOUS AGENTS ON WESTERN-BENTONITE-BONDED SAND

Agent Added	*Per Cent Added*	*Moisture Loss, Per Cent — Time, min.* 30	60	90	120	180	360
None (blank)	—	4.0	7.1	9.7	12.3	16.2	27.7
Lithium Chloride	2.0	2.8	5.3	7.5	9.5	13.9	23.9
	5.0	2.9	4.6	6.7	8.7	11.6	19.7
Potassium Acetate	5.0	5.0	8.6	11.3	13.9	18.1	29.4
Zinc Chloride	5.0	5.2	8.3	10.9	12.9	16.9	27.9
Cereal Binder No. 1*	5.0	3.5	7.2	9.2	12.2	15.7	27.1
	10.0	4.8	7.8	9.9	12.3	15.8	26.8
	25.0	3.8	7.0	8.4	10.8	14.8	25.0
Ethylene Glycol	5.0	6.2	8.4	11.1	13.6	18.3	29.1
Sulphuric Acid	5.0	6.5	9.8	12.7	14.9	19.6	29.7
Phosphoric Acid	5.0	4.5	7.5	10.5	12.8	17.7	27.6
Dextrin*	25.0	5.1	8.5	10.8	13.3	17.8	28.9

13. Table 3 indicates that western-bentonite-bonded sands dried out more slowly than southern-bentonite or fire-clay-bonded sands. Most treating agents were not effective on western bentonite and only lithium chloride gave an appreciable reduction in the rate of drying-out.

14. Table 4 again points to the value of lithium chloride on southern-bentonite-bonded sands, with calcium chloride and barium chloride effective to a lesser extent. Table 5 indicates that both lithium chloride and calcium chloride are very effective on fire-clay-bonded sands. Table 6 again points to the value of lithium chloride and calcium chloride additions when applied to western-bentonite-bonded sands.

Effect of Lithium and Calcium Chlorides on Properties

15. Table 7 shows that calcium chloride had little effect on the mechanical properties of a southern-bentonite-bonded sand. Previous tables have shown, however, that calcium chloride is less effec-

* Added dry to the clay sand mixture.

Table 4

EFFECT OF VARIOUS AGENTS ON SOUTHERN-BENTONITE-BONDED SAND

Agent Added	Per Cent Added	Moisture Loss, Per Cent — Time, min. 30	60	90	120	180	390
None (blank)	—	6.2	9.6	13.8	16.1	21.1	32.8
Lithium Chloride	2.0	3.6	9.4	11.5	14.6	20.4	34.0
	5.0	3.7	7.9	9.8	12.7	18.1	29.6
	10.0	3.5	7.2	8.8	11.3	14.7	22.6
Calcium Chloride	2.0	6.5	10.3	13.5	16.5	22.4	35.2
	10.0	5.7	7.0	9.9	11.8	15.9	26.4
Phenol	5.0	6.9	11.1	15.3	18.7	24.6	39.1
Barium Carbonate	5.0	7.1	9.8	13.4	16.3	21.7	36.4
Barium Chloride	5.0	7.1	11.4	13.8	17.0	20.6	28.0
	10.0	5.9	10.0	12.6	15.8	18.7	25.2
Zinc Sulphate	5.0	5.6	10.3	12.6	16.2	18.6	26.3
	10.0	6.4	10.0	13.3	17.3	19.1	27.6

tive than lithium chloride. A 10 per cent addition of lithium chloride to the southern-bentonite-bonded sand caused a drop in both green and dry strength. Smaller additions, which were effective in reducing the drying rate, had no material effect on strength.

16. The green strength of the fire-clay-bonded sand was not materially affected by any additions of these chlorides. Two per

Table 5

EFFECT OF VARIOUS AGENTS ON FIRE-CLAY-BONDED SAND

Agent Added	Per Cent Added	Moisture Loss, Per Cent — Time, min. 30	60	90	120	180	390
None (blank)	—	6.4	10.8	16.5	18.7	27.4	46.8
Lithium Chloride	2.0	5.2	8.5	8.9	14.1	19.3	34.1
	5.0	3.9	6.5	8.1	9.6	13.7	21.3
	10.0	1.8	2.4	3.8	4.2	5.9	9.3
Calcium Chloride	2.0	4.5	7.6	10.7	13.7	19.0	34.5
	5.0	4.2	6.8	8.8	11.1	14.6	34.6
	10.0	2.1	3.5	4.0	5.3	6.7	11.8
Phenol	5.0	6.6	11.0	15.8	19.6	26.4	44.2
Barium Carbonate	5.0	5.9	9.8	13.0	16.5	22.1	38.7
Barium Chloride	5.0	4.9	8.7	11.3	12.1	14.6	21.9
	10.0	4.4	8.3	10.4	11.9	14.0	21.0
Zinc Sulphate	5.0	6.5	10.3	13.8	15.0	17.3	25.4
	10.0	4.6	8.3	10.7	11.7	13.9	20.4

Table 6

EFFECTS OF VARIOUS AGENTS ON WESTERN-BENTONITE-BONDED SAND

Agent Added	Per Cent Added	Moisture Loss, Per Cent — Time, min. 30	60	90	120	180	360
None (blank)	—	4.0	7.1	9.7	12.3	16.2	27.7
Lithium Chloride	2.0	2.8	5.3	7.5	9.5	13.9	23.7
	5.0	2.9	4.6	6.7	8.7	11.6	19.7
	10.0	1.1	2.3	4.1	4.4	5.9	11.6
Calcium Chloride	2.0	4.2	6.6	9.4	11.6	15.5	25.2
	5.0	3.0	5.4	7.5	9.6	12.9	21.5
	10.0	2.6	4.7	6.2	7.7	10.0	16.2
Barium Chloride	10.0	4.5	6.6	9.8	11.6	15.8	26.2
Zinc Sulphate	10.0	5.0	7.6	10.8	13.2	17.0	28.0

cent calcium chloride had little effect on dry strength, while larger additions substantially increased this value. This would be desirable in some applications and undesirable in others.

Effect of Lithium and Calcium Chlorides on Hot Strength

17. Table 8 shows that lithium chloride, which was most effective in reducing the drying rate, caused a substantial drop in hot

Table 7

EFFECT OF LITHIUM AND CALCIUM CHLORIDE ADDITIONS ON MECHANICAL PROPERTIES OF SAND

Type Bond	Addition Kind	Per Cent	Green Permeability	Green Compression, lb. per sq. in.	Dry Compression, lb. per sq. in.
Southern Bentonite	None (blank)	—	284	8.1	53
	Calcium Chloride	2.0	287	8.6	55
		5.0	287	8.5	58
		10.0	300	8.0	56
	Lithium Chloride	2.0	275	8.1	58
		5.0	300	8.2	46
		10.0	287	7.4	34
Fire Clay	None (blank)	—	161	8.4	40
	Calcium Chloride	2.0	146	8.2	38
		5.0	156	7.7	63
		10.0	142	8.0	89
	Lithium Chloride	2.0	146	8.0	23
		5.0	173	8.0	41
		10.0	178	7.7	73

strength of the southern-bentonite-bonded sand and a lesser drop in the fire-clay-bonded sand. Calcium chloride also caused some drop in hot strength of both sands.

Effect of Cereal Binders on Drying-out Rate

18. Table 9 shows that cereal binders were effective in reducing the rate of drying-out of fire-clay and southern-bentonite-bonded sand but less effective with western-bentonite-bonded sand. Sucrose was effective only with the fire-clay and the sulphite binder was particularly effective with fire-clay. It also will be noted that small additions of calcium and lithium chloride reduced the drying rate of the fire-clay-bonded sand as much as very large additions of cereal binder.

Table 8

HOT STRENGTH OF TREATED SAND

Type Clay	*Addition* *Kind*	*Per Cent*	*Hot Compression Strength, lb.* *500*	*1000*	*1500*	*2000° F.*
Southern Bentonite	None (blank)	—	33	42	55	64
	Calcium Chloride	5.0	—	—	—	50
		10.0	45	45	62	42
	Lithium Chloride	5.0	—	—	—	29
		10.0	—	—	—	20
Fire Clay	None (blank)	—	42	71	81	201
	Calcium Chloride	5.0	—	—	—	142
		10.0	93	118	169	106
	Lithium Chloride	5.0	—	—	—	198
		10.0	—	—	—	120

Drying-out Behavior of Naturally-bonded and Synthetic Sands

19. At this point in the investigation, it was apparent that the drying rate could be reduced and it was necessary to determine how much improvement was necessary to provide a satisfactory sand. Naturally-bonded sands, and also synthetic sands, treated with oil had been declared to be satisfactory by users. Therefore, their drying behavior was determined.

20. The weaker Sandusky sand was used as received, while the stronger Gallia sand was mixed with 25 per cent Michigan City sand to give green strengths comparable with the synthetic sands used. Table 10 shows that the percentage moisture loss in naturally-

Table 9

EFFECT OF FURTHER ADDITIONS ON ALL TYPES OF SAND

Addition Agents	*Per Cent Added*	*Moisture Loss, Per Cent* — *Time, min.* 30	60	90	120	180	390
Fire Clay							
None (blank)	—	4.4	7.5	11.1	14.0	18.9	34.4
Cereal Binder No. 1	10.0	3.7	6.5	8.9	11.0	15.0	26.2
	25.0	3.1	5.9	8.1	10.4	13.7	23.8
Cereal Binder No. 2	10.0	4.0	7.0	9.8	11.8	15.2	26.8
	25.0	4.0	7.0	9.3	11.2	14.6	25.2
Cereal Binder No. 3	10.0	4.0	7.1	9.7	11.4	15.6	26.7
	25.0	4.4	7.1	9.0	11.3	14.9	25.5
Sulphite Binder	10.0	3.5	6.1	7.9	9.8	13.2	22.3
	25.0	3.2	5.4	6.7	8.4	11.8	19.2
Sucrose	10.0	4.4	7.5	9.8	12.1	16.0	26.8
	25.0	3.4	6.0	8.0	9.8	13.0	22.9
Calcium Chloride	0.5	3.9	6.9	9.2	11.6	17.1	28.0
	1.0	4.0	6.6	9.1	11.0	14.9	26.2
Lithium Chloride	0.5	3.5	6.3	8.9	11.4	15.8	27.7
	1.0	3.3	6.2	8.4	10.3	14.4	24.7
Southern Bentonite							
None (blank)	—	6.9	9.5	11.8	14.2	19.0	32.3
Cereal Binder No. 1	10.0	3.0	6.3	9.6	11.6	16.1	30.4
	25.0	4.8	7.9	10.4	13.0	17.8	31.4
Cereal Binder No. 2	10.0	4.3	7.0	10.5	13.2	17.8	28.1
	25.0	4.4	7.2	10.7	13.8	17.9	30.6
Cereal Binder No. 3	10.0	4.4	7.4	10.2	12.9	18.1	30.8
	25.0	4.4	6.9	10.2	12.4	17.1	29.6
Sucrose	10.0	5.7	7.5	10.2	12.9	16.4	30.2
	25.0	3.0	6.1	8.5	10.3	14.9	28.2
Western Bentonite							
None (blank)	—	4.0	7.1	9.7	12.3	16.2	27.7
Cereal Binder No. 1	10.0	4.8	7.2	9.2	12.2	15.7	27.1
	25.0	3.8	7.8	9.9	12.3	15.8	26.8
Cereal Binder No. 2	10.0	4.8	7.0	8.4	10.8	14.8	25.0
	25.0	4.0	7.9	10.4	12.9	16.2	26.9
Cereal Binder No. 3	10.0	4.2	6.5	9.1	11.9	15.0	25.5
	25.0	4.8	7.5	9.7	12.2	16.4	27.6
Sucrose	10.0	4.2	7.0	9.1	11.1	16.4	25.8
	25.0	4.5	7.0	9.7	12.1	16.3	26.4

Table 10

RATE OF DRYING OF NATURALLY-BONDED SAND

	Moisture Loss, Per Cent					
	Time, min.					
Sand	*30*	*60*	*90*	*120*	*180*	*390*
Gallia Red plus 25 per cent Michigan City	2.6	4.3	6.1	8.3	11.7	21.8
Sandusky	2.5	5.1	7.1	8.9	12.7	23.9

bonded sands is lower than with synthetic sands. Table 11 shows that actual moisture loss is as great or greater. It seems, therefore, that these naturally-bonded sands do not dry out slower than synthetic sands but that the loss is less important because they are workable over a wider moisture range.

Table 11

COMPARISON OF DRYING RATE OF NATURALLY-BONDED AND SYNTHETIC SAND

Sand		*Tempering Water, per cent*	*Total Moisture Loss in 390 Min., per cent*	*Actual Water Loss in 390-Min.-Grams per 1000 Grams Sand*
				Natural Snythetic
Natural	Gallia	6.0	21.8	13.1
	Sandusky	5.0	23.9	11.9
Synthetic	Fire Clay	3.5	34.4	12.1
	Southern Bentonite	2.5	32.3	8.1
	Western Bentonite	2.5	27.7	6.9

21. This is true also of fire-clay-bonded sands which give less trouble from drying-out in the foundry than the bentonites, although the rate of moisture loss is greater in the fire-clay-bonded sands.

Effect of Fuel Oil Additions on Drying-out

22. As shown in Table 12, fuel oil, added a short time before the mixer was dumped, had little effect in reducing the rate of drying-out.

23. It was found that check results were more consistently obtained in all tests in the periods of longer drying and it is suggested that comparisons between tests be made on such basis.

24. The system sand in Table 13 is composed principally of burned core sand, with a small amount of bank sand and sea coal.

Table 12

Effect of Oil Additions on Drying Rate

Clay Bond	*Fuel Oil* Per Ton Sand, Qts.*	*Moisture Loss, Per Cent**—Time, min.* 30	60	90	120	180	390
Southern Bentonite	—	6.4	8.7	11.1	13.2	17.9	30.4
	5.9	3.9	7.6	10.0	12.6	16.6	29.5
	11.8	5.0	8.2	11.3	13.7	18.0	29.8
	17.6	4.6	7.2	9.7	12.5	16.4	26.6
Fire Clay	—	4.4	6.7	9.2	12.3	15.6	29.4
	5.9	4.2	6.8	9.4	11.7	16.2	29.7
	11.8	3.9	6.4	8.5	11.1	15.3	28.9
	17.6	3.4	6.4	8.6	11.0	15.4	28.1
Western Bentonite	—	3.8	6.8	9.2	11.3	15.6	25.9
	5.9	3.1	6.2	8.6	9.9	14.9	24.2
	11.8	4.4	7.3	9.6	12.0	16.1	26.3
	17.6	4.7	7.0	9.6	11.2	15.6	26.8

The clay used is a combination of one-half fire clay and one-half southern bentonite. There are 60 tons of sand in the system, which is used three times per hour. Therefore the 5 gal. of fuel oil per hour is added to 180 tons of sand. Since not all of it is burned out, there must be a substantial reserve of oil in the sand at all times. The foundry finds a definite improvement from the addition of the 5 qts. of fuel oil to the facing sand. This reduced the 390 min. drying-out from 27.4 per cent to 23.4 per cent, which gives some measure of what constitutes an appreciable improvement.

Table 13

Rate of Drying of Commercial Synthetic Sands to Which Oil Is Added

Sand	*Moisture Loss, Percent — Time, min.* 30	60	90	120	180	390
System Sand—5 gal. fuel oil added per ton	2.9	5.6	7.9	11.3	14.3	27.4
Facing Sand—Made from system sand plus 5 qts. of fuel oil	2.9	5.2	6.8	8.8	12.4	23.4

25. Table 14 shows that steel foundry sands have a lower rate of loss than malleable or naturally-bonded sands, despite their high permeability. This is due possibly to the cereal binder in the mixture.

26. The malleable facing sand was satisfactory in use when the

* No. 3 Fuel Oil, specific gravity 0.8.

** Based on weight of water added.

Table 14

COMPARISON OF DRYING RATE OF VARIOUS SANDS

Clay Bonded Sand	*Per Cent Addition*	*Per Cent Tempering Water*	*Moisture Loss in 390 Min., Per Cent*
Fire Clay		3.5	34.4
Southern Bentonite		2.5	32.3
Western Bentonite		2.5	27.7
Fire Clay Bonded			
Cereal Binder No. 1	10.0	3.5	26.2
Sulphite Binder	10.0	3.5	22.3
Lithium Chloride	0.5	3.5	27.7
Southern Bentonite Bonded			
Cereal Binder No. 1	10.0	2.5	30.4
Lithium Chloride	5.0	2.5	29.6
Calcium Chloride	10.0	2.5	26.4
Western Bentonite Bonded			
Lithium Chloride	2.0	2.5	23.9
Malleable System Sand Containing Oil	—	3.1	27.4
Malleable Facing Sand Containing Oil	—	3.3	23.4
Steel Foundry System Sand	—	3.1	20.0
Steel Foundry Facing Sand	—	3.5	17.7
Gallia Naturally-bonded Sand		6.0	21.8
Sandusky Naturally-bonded Sand		5.0	23.9

moisture loss was 23.4 per cent in 390 min., which meant that it was losing water at about the same rate as the naturally-bonded sands. Since the first three synthetic sands lost from 27.7 to 34.4 per cent moisture, it might be assumed that a substantial improvement is necessary. This does not take into account the fact that the original synthetic sands were made from silica sand and bond only, with no fines present, as is the case in a regularly used synthetic sand. Therefore, the condition is exaggerated and the test a severe one. It seems likely that the presence of fines would reduce the rate of drying-out about 5 per cent and that only a further reduction of 5 per cent would be required. Many of the treating agents used accomplished this quite easily.

SUMMARY

27. The results of this investigation may be summarized as follows:

1. Several addition agents were used which appreciably reduced the rate of drying-out of synthetic sands.

2. A comparatively small reduction in the rate of drying-out is of appreciable benefit.

3. Naturally-bonded sands lost more water in any particular time, but the percentage of moisture loss was lower than for synthetic sands because of the higher quantity originally present.

4. Fuel oil additions did not appreciably reduce the rate of drying-out in experimental work but are of value in commercial use. Sands treated with fuel oil felt wetter than was actually the case and were more workable. Since the chief disadvantage of dry sand is that it is brittle, oil additions may be of value in that they increase resilience and workability.

DISCUSSION

Presiding: L. B. KNIGHT, National Engineering Co., Chicago, Ill.

Co-Chairman: F. L. WEAVER, Great Lakes Foundry Sand Co., Detroit, Mich.

M. E. GANTZ[1]: Did the author ever do any work on checking how long these sands could be regenerated? That is, whether or not, when mulled up the second, third or fourth time, they would achieve about the same physical properties?

MR. DUNBECK: No, we have not done that but we have speculated about it. The sand, back from the face of the mold, will not reach any particularly high temperature. If it does get warm, it probably would be of benefit. It would drive the moisture from the lithium chloride and make it more effective. We think it would regenerate.

MR. GANTZ: We have done a certain amount of work in our plant with some of these electrolytes with something of the same thought in mind, and we have had the experience that, by the addition of the electrolyte, the sand feels drier and it becomes necessary to carry a higher moisture content to satisfy the foundry and the molders that the sand has been tempered properly. Is that true?

MR. DUNBECK: We found that to be true to some extent on some materials. That is one thing that inclined us towards fuel oil, if it could be used, or one of the sulphite pitch binders, or something of that sort, because we did not notice any dryness in such sands. The sulphite binder made it feel definitely wetter. Another reason why we like the sulphite binder is because other chemicals will reduce the sintering point, but we do not believe sulphite binders will have any effect on sintering.

MR. GANTZ: Sintering does not affect us. Keeping the moisture at a minimum and keeping it workable is important.

CHAIRMAN KNIGHT: Did you make any check on the corrosive action of these chlorides? Your lithium chloride very definitely will ruin the hoppers and mechanical equipment.

MR. DUNBECK: I expect that is true. We do not like these chlorides

[1] American Magnesium Corp., Cleveland, Ohio.

them at some length because we thought they would teach us something, but I am not much inclined to use them myself.

CHAIRMAN KNIGHT: When you mentioned your percentages on the drying-out of the sand in the box, did you test all the sand or just test the surface of it?

MR. DUNBECK: No, we mixed it all. That means the surface was dried, the balance was not and the test result was the average.

There is one thing that is not brought out in any of these percentages, namely, the fact that when a high percentage of lithium chloride is used, a very great improvement is shown. We talk in percentages, but in actual use, when the sand is made up with no treating agent in it, the surface is perfectly dry in one hour. When as much as 10 per cent lithium chloride is used, which was mentioned as being very effective, the surface of that sample is still perfectly damp and moist after 22 hours of standing in the open air. The lithium chloride is remarkable for keeping the sand moist.

H. H. FAIRFIELD[2]: I would like to mention temperature in connection with these synthetic sands. The drying-out is a function of temperature. Sometimes it takes place over a fairly short period. Have you investigated the effect that fairly high temperatures have on the compounds?

MR. DUNBECK: We have not studied the effect of temperature. We realized that temperature and humidity were so important that all these tests were conducted in a room at constant temperature and constant humidity. We eliminated those variables in an attempt to get at the basic facts first. I do not think there is any doubt that the higher temperature will cause a much more rapid drying-out.

MR. FAIRFIELD: But would the results be comparable if the tests were run under the same conditions?

R. L. CLELAND, JR.[3]: Don't you think that it is worth while to mention the fact that if we reduce the vapor pressure, we increase the tendency of the sand to pick up moisture in a damp atmosphere at the same time? While these chlorides may serve to keep the sand from drying out, they also will increase the tendency of the sand to pick up water and it may become unworkable if too much lithium or calcium chloride is used.

MR. DUNBECK: I think it is possible. We are skeptical about the sand becoming unworkable. In the case of skin-dried or air-dried molds, it would make the sand hygroscopic, which might be quite undesirable.

DR. H. RIES[4]: Although Mr. Dunbeck has said he does not like chlorides, I would like to ask him if he tried sodium chloride as well as calcium chloride. The reason I ask is because experiments which have been made on mixing both of these chlorides with samples of the same clay have shown that the clay which had sodium chloride in it lost moisture at a less rapid rate than the clay which had the calcium chloride in it.

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[2] Mines and Geology Branch, Canadian Department of Mines and Resources, Ottawa, Canada.
[3] Eastern Clay Products, Inc., Philadelphia, Pa.
[4] Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

MR. DUNBECK: No, I did not try that. It seems incredible. I accept your statement of fact, though.

RUSSELL MANLEY[5]: We have found that the sintering point of the sand is directly related to the fusion point of the clay. The addition of calcium or lithium is going to affect the fusion point of the clay tremendously. We can take silica sand, which has a fusion point of about 3100°F. or better, and by the addition of lime, soda ash, feldspar, etc., make a glass with a fusion point of a little better than 2000°F.

MR. DUNBECK: I doubt that these chlorides will affect the fusion point for this reason. Toward the latter part of this work, we found that additions of as little as ½ per cent of lithium chloride was effective, with 2½ per cent of clay present. So the amount of flux we are putting in the sand is ½ per cent of 2½ per cent and that is probably a lot less flux than we find naturally in a good many clays that are being used successfully. However, in any careful measurement, that should reduce the sintering point. Now if we start with ½ per cent and these chlorides regenerate so we are able to drop them to ¼ per cent or ⅛ per cent, maybe they will work successfully.

MR. CLELAND: In actual practice with calcium chloride in the sand, there was no increase in sintering or burning. It was easier, if anything, to clean castings with about 1 per cent calcium chloride in the sand.

MR. MANLEY: With what kind of clay?

MR. CLELAND: Southern bentonite. We had 0.8 per cent of calcium chloride in the sand mixture. The combination of kaolinite and goulac strongly resists drying-out. At the same time, kaolinite and goulac give the hardest air-dried skin we have ever seen and gives it very quickly. The sand beneath the surface will hold its moisture for a long time; the skin seems to form a seal.

MR. GANTZ: We have been carrying some of these electrolytes in the heap for some time and we have found that the ability of these electrolytes to precipitate the clay or to reduce the colloidal condition and decrease the efficiency of the binder over a long period of time, is not to be underestimated. Of course, we carry the electrolytes in higher percentages than you can use.

MR. DUNBECK: How high?

MR. GANTZ: We have gone up to about 15 per cent of the clay, and we use the electrolytes for other purposes, too. I have noticed that these chlorides reduce the green strength of the sand very materially.

CHAIRMAN KNIGHT: Does the flowability of that sand decrease?

MR. GANTZ: No. We get an increase in flowability with our machine.

CHAIRMAN KNIGHT: Does it get a gummy "feel"?

MR. GANTZ: No. It gets a sharper "feel," rather than a gummy "feel."

DR. RIES: Did you mention the percentage of electrolytes in that clay?

MR. GANTZ: I said about 15 per cent of the clay.

DR. RIES: That is a pretty good amount.

MR. GANTZ: Yes. We allowed the electrolyte content to decrease very much, but they are the most effective treating agents. We went into

[5] Manley Sand Co., Rockton, Ill.

considerably, and we stopped analyzing for it, but for at least 3 weeks after the electrolyte additions were stopped, the reduction in green strength was still noticeable.

CO-CHAIRMAN WEAVER: I would like to suggest that, for rapid molding, what seems to be relatively slight improvement might be of great benefit for that class of work. On the other hand, in slower molding, say 6 hrs. (From Table 1), just by a simple calculation, subject to correction by Mr. Dunbeck, I would think that even an arbitrary 20 per cent slower drying time would only represent 1 hr. and 12 min. in the difference between a treated sand and an untreated sand; and from the same Table, a 1-hr. drying time would only represent 8.4 minutes' difference in drying-out of treated sand (lithium). In using the 20 per cent suggested improvement in a storage pile of facing sand, while the surface no doubt was pretty well dried out, the average of the entire box showed the improvement as suggested.

CHAIRMAN KNIGHT: Did you make any checks on the drying-out of the surface with the sands containing the cereal binder, and the sulphite binder, as compared with the entire mass?

MR. DUNBECK: It is a little difficult to rely on observation on those things and our opinion may not be valuable, but in the case of the cereal binder, the appearance was that of a rather pronounced drying-out, although the results contradicted it. In the case of the sulphite binder, one could see that the surface appeared still moist. Those sulphite binders are very interesting. I do not think they are going to injure any property of the sand, except that they may raise the dry strength. In some cases, it would be advantageous and in other cases, probably a disadvantage.

MEMBER: The electrolyte would retain the moisture and sulphur. Would that interfere with air-drying processes of those sands?

MR. DUNBECK: Yes, I think it would.

MEMBER: That is one thing that would throw us off. We like to have a high air-drying strength to handle molds better.

MR. DUNBECK: I think you would have an almost impossible condition if you want sand that will air-dry fast but still stay workable while you patch it. You have to shoot for either one or the other.

MEMBER: In your case, you mentioned that the sand held moisture after 30 hours.

MR. DUNBECK: That is true. A very large addition was used.

Report of Survey on Foundry Instruction in Engineering Schools

In a letter addressed to the deans of engineering schools, the purpose of this survey of foundry instruction was stated as follows:

"The ever growing demand for technically trained men in the foundry industry has prompted the AMERICAN FOUNDRYMEN'S ASSOCIATION to make a survey of the engineering schools of the country to study what is being done to interest young men in becoming foundry engineers. This survey is the beginning of an activity which is being conducted with the hope that:

"1. The schools will become more conscious of the foundry industry's needs.

"2. The schools will be informed of the most modern type of foundry instruction.

"3. More engineering graduates will be inspired to enter the foundry industry.

"........... It is our purpose further to stimulate greater interest in foundry engineering as a profession among college students by providing information on the needs of the industry. In another activity of this Committee, through the A.F.A. chapters, we are endeavoring to bring about closer cooperation between the foundry industry and the colleges. By virtue of the local interest of each chapter, we believe this can be done better than through this committee alone."

The questionnaire which accompanied the foregoing letter follows:

Table 1

QUESTIONNAIRE ON FOUNDRY INSTRUCTION IN COLLEGES FOR THE COMMITTEE ON COOPERATION WITH ENGINEERING SCHOOLS OF THE AMERICAN FOUNDRYMEN'S ASSOCIATION

1. *In what department is foundry practice taught?*
2. *Education and experience of each foundry instructor:*

(a)	Degree	1	2	3	4
(b)	Title	1	2	3	4
(c)	Years of practical experience	1	2	3	4
(d)	Years of teaching experience	1	2	3	4
(e)	Consulting work	1	2	3	4
		Yes....	Yes....	Yes....	Yes....
		No....	No....	No....	No....

NOTE: This report was presented before the Foundry Industry and Engineering Training Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

3. *Proportion of students receiving elementary foundry training:*

Course	*(a) Required*	***(b) Elective***
All	....	....
C.E.	....	....
M.E.	....	....
E.E.	....	....
Ch. E.	....	....
Met. E.	....	....

4. *Advanced foundry required:*
Yes.... No.... What Curricula?
Elective:
Yes.... No.... What Curricula?

5. *Number of students given foundry instruction:*

	1938-39	*1939-40*	*1940-41*
Elementary Course	....	....	....
Advanced Course	....	....	....

6. *Number and type of (semester or quarterly) credits in foundry courses:*

	Lecture	*Recitation*	*Laboratory*
(a) Elementary Course	....	....	....
(b) Advanced Course	....	....	....

7. *Number of graduates who chose foundry engineering jobs:*
1941.... 1935-1941....

8. *Instruction given in:*

	Yes	*No*
(a) Pattern design	....	....
(b) Patternmaking	....	....
(c) Molding	....	....
(d) Core making	....	....
(e) Sand control	....	....
(f) Metal control and testing	....	....
(g) Casting defects	....	....

9. *Research work performed:*

	Yes	*No*
(a) By staff	....	....
(b) By students	....	....

10. *Attendance of foundry staff at technical A.F.A. meetings:*
(a) National .... (Years since 1935 ....)
(b) Regional .... (Years since 1935 ....)
(c) Chapter ..... (Number of meetings attended during 1940-41 ....)

11. *Are any A.F.A. publications used regularly as textbooks in teaching?*
    (a) Design
    (b) Patternmaking
    (c) Foundry work

12. (a) *Name of Institution:* ....
    (b) *Name and title of person answering questionnaire:*
    ....

Table 2

TABULATED RESULTS OF SURVEY

	No. of Questionnaires
Sent Out	140
Returned with Data	35
Returned, Showing No Foundry Courses Offered	20
Not Returned	85

1. *Departments in which foundry practice is taught:*

	No. of Schools
Mech. Engrg.	18
Shops	6
Ind. Engrg.	3
Mat. or Metal Proc.	2
Met. Engrg.	1
Gen. Engrg.	1
Not listed	4

2. *Education and experience of each foundry instructor:*

No. of Schools	*No. of Instructors*
2	4
7	3
6	2
18	1

(a)

Degree	*No. of Instructors*
Ph.D.	3
M.E.	4
M.S.	18
B.S.	19
B.A.	2
Ind. Arts	2
None	11

(b)

Title	*No. of Instructors*
Prof.	1
Assoc. Prof.	7
Asst. Prof.	10
Instructor	27
Asst.	3
Not listed	15

(c) and (d)

Years	*Instructors with Practical Experience*	*Instructors with Teaching Experience*
Over 25	2	5
20 to 25	5	10
10 to 20	14	10
5 to 10	7	11
2 to 5	19	14
Less than 2	5	6

(e) *Consulting work:* Done by 14 instructors

3. *Number of schools giving elementary foundry training:*

(a) *Courses*	*Required by*	(b) *Elective in*
M.E.	31	1
E.E.	16	3
Chem. Engrg.	5	6
Ind. Engrg.	5	
Aero. Engrg.	4	
Met. Engrg.	3	3
C.E.	1	4
Petrol. E.	2	
All	3	10

4. *Number of schools giving advanced foundry training:*

(a) *Courses*	*Required by*	(b) *Elective in*
M.E.	4	4
Aero. E.	2	
Ind. E.	3	
Met. E.	1	1
All	1	7

5. (a) *Number of students in elementary courses:*

	No. of Schools		
No. of Students	*1938-39*	*1939-40*	*1940-41*
Over 400	1	1	1
300 to 400	4	3	6
200 to 300	7	9	5
100 to 200	10	8	10
50 to 100	5	6	4
Less than 50	8	8	9
Total	5597	5592	5880

(b) *Number of students in advanced courses:*

	No. of Schools		
No. of Students	*1938-39*	*1939-40*	*1940-41*
200	1	1	1
50 to 100	1	2	2
25 to 50	4	3	3
Less than 25	7	7	7

6. *Hours per term:*

Hours	*Elementary Course* *Lect.*	*Rec.*	*Lab.*	*Advanced Course* *Lect.*	*Rec.*	*Lab.*
1	21	3	2	9	2	1
2	2	2	13	0	1	2
3	3	0	8	0	0	4
4	0	0	6	0	0	4
6	0	0	2	0	0	0

7. *Number of graduates who chose foundry engineering jobs:*

1941: 34
1935-41: 26

8. *Instruction given in:*

	No. of Schools
(a) Pattern design*	27
(b) Patternmaking*	25
(c) Molding	35
(d) Core making	34
(e) Sand control	28
(f) Metal control and testing	23
(g) Casting defects	32

9. *Research work performed:*

(a) By staff—14 instructors
(b) By students—9 schools

10. *Number of instructors attending A.F.A. meetings since 1935:*

(a) National:

Years	*No. of Instructors*
1	2
3	1
5	5
6	4

(b) Regional:

Years	*No. of Instructors*
1	1
2	5
3	3
4	2
5	1

(c) Chapter (during 1940-41):

No. of Meetings	*No. of Instructors*
2	3
3	1
4	1
5	3
6	1
12	1

* Two schools had separate courses in pattern design and patternmaking.

11. *A.F.A. publications used as texts or reference:*

Publication	*No. of Schools* Text	Reference
Cast Metals Handbook	2	1
Testing and Grading Foundry Sands and Clays	1	1
The Microscope in Elementary Cast Iron Metallurgy Preprint 38-3	1	
All publications		10

CONCLUSIONS

In looking over the returns from the various schools, there are several general conclusions which might be made.

1. The Department of Mechanical Engineering in most schools teaches foundry. This will require that the instructors make special efforts to acquaint themselves with the metallurgical aspects of the industry. Opportunity should be afforded the staff to study in this field.

2. There are many schools where the number of students per instructor is too great. This condition would indicate that many courses are still of the shop type, rather than of the engineering laboratory type.

3. There is too much emphasis placed on molding, core making and making castings instead of on the science or technology of foundry practice.

4. There is still room in most schools for more men of faculty rank to teach foundry work. This recognition is essential if proper instruction is to be given.

5. It would be advisable for more staff members to participate in research and consulting activities.

6. A survey should be made in each school to see if all required to take foundry courses actually need to. This might help decrease teaching loads.

7. The appearance of many courses in advanced foundry practice is encouraging.

8. While the committee feels that the number of graduates who are working in the foundry industry is greater than this survey would show, there are still too few when we consider the total number of men who have taken advanced foundry work in school. Some responsibility here lies with the industry itself.

9. The attendance of the foundry instructors at regional, chapter, and national meetings should be much improved.

ACKNOWLEDGMENT

The committee wishes to thank everyone who contributed to make the results of this survey of value.

Respectfully submitted,

COMMITTEE ON COOPERATION WITH ENGINEERING SCHOOLS

F. G. SEFING, *Chairman*.

H. BORNSTEIN	P. E. KYLE
C. W. BRIGGS	J. H. LANSING
C. H. CASBERG	J. T. MACKENZIE
R. R. DEAS, JR.	S. D. MOXLEY
C. J. FREUND	S. C. MASSARI
JOHN GRENNAN	J. F. OESTERLE
H. H. JUDSON	F. G. STEINEBACH

DISCUSSION

Presiding: F. G. SEFING, International Nickel Co., New York, N. Y.

J. F. OESTERLE[1]: The low figure given for the percentage of students accepting jobs, or finding jobs in the foundry industry, is not a reflection upon the interests of students as much as it is upon the ability of the foundry to absorb them. This low figure is not in entire agreement with the fact that we are keeping pace in our education with development in the industry. I think that we in education are far ahead of the industry. As a whole, it is not, as yet, ready for, nor does it know how to use, a graduate engineer, but I do think a need for them is developing, and it is encouraging to note that we get inquiries.

Progress is slow in our efforts to sell the foundry industry on college graduates. There are many obstacles to overcome before we will be permitted to demonstrate that we have a place. The old-timer foundryman, who has done an excellent job and brought the industry a long way, is reluctant to hand over responsibility to technical graduates even though modern technology lies beyond his grasp. Foundry conferences are doing much to pave the way. Old-timers, through their college trained sons, have broken a lot of ice. The AMERICAN FOUNDRYMEN'S ASSOCIATION has aided tremendously. Perhaps we are looking for the answer too soon.

CHAIRMAN SEFING: What Prof. Oesterle has said touches on one of the main problems of this Committee on Cooperation with Engineering Schools. Maybe the name of the committee should be changed to denote cooperation with the foundries rather than with the schools, because the schools are cooperating, and I think that is a very pertinent point.

[1] University of Wisconsin, Madison, Wis.

C. J. FREUND[2]: I think too, in accounting for the number of men that go into the industry, the records will not show boys who are employed by a large corporation, and who may afterwards get into the foundry division of that corporation.

P. E. KYLE[3]: Would it be fair to make some survey of the foundry industry itself to find out how many men they have employed? That is such an important factor for this work. I agree with everyone that we cannot find the records at the schools as complete as we should have them. Perhaps some survey through the industry itself would help.

CHAIRMAN SEFING: That is a very good point.

BRUCE WHITING[4]: We have taken two graduate engineers who have both gone into other work, one a metallurgist and one a mechanical engineer, and they are doing a very good job.

R. E. WENDT[5]: Several of the students I have had have gone into the foundry directly, but most of them are going in with manufacturers of foundry equipment.

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[2] University of Detroit, Detroit, Mich.
[3] Massachusetts Institute of Technology, Cambridge, Mass.
[4] Michigan Steel Casting Co., Detroit, Mich.
[5] Purdue University, West Lafayette, Indiana.

The College Graduate Looks at the Foundry Industry

By C. J. Freund*, Detroit, Mich.

Abstract

In this paper the writer tells of a survey made by himself and professors from two other engineering schools among engineering seniors regarding their views of the foundry industry as a career. The results were exceedingly enlightening and showed that foundry executives are largely responsible for not visioning the possibilities of their industry to the engineering school student and staff. The writer discusses the circumstances and conditions which have caused these reactions, urging the foundry industry to become active in competing for the services of engineering graduates. He further advocates a change in the attitude of the instructor in charge of foundry instruction and states that the industry offers many opportunities to the engineering graduate as a career.

1. Many here doubtless attended the college training session at the Chicago Convention of this Association two years ago and remember the young man who met with us and who wanted strongly to work in a foundry but could not find a job. He was intrigued by foundry technique. He had completed all the undergraduate foundry courses he could get in the University of Minnesota, and had gone on to a master's degree in foundry technology. He wished to make the foundry his life work, and applied for employment in practically every foundry in the midwest, but nobody wanted him. He made a splendid impression upon all of us. Recruiting officials of the power, chemical, telephone and automobile industries fight over men of his type, but he could not beg his way into a foundry.

2. It seems to me that the case of this young man just about tells the story. With notable—and most occasional—exceptions, foundrymen are little interested in college trained men. While personnel officers of General Motors, Westinghouse, Standard Oil, Pratt and Whitney, General Electric and many other corpora-

* University of Detroit, College of Engineering.
Note: This paper was presented before the Foundry Industry and Engineering Training Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

tions come to the University of Detroit, and to other institutions, to hire graduates, nobody has come to the University to hire for a foundry, neither this year nor any other year.

STUDENT VIEWPOINT

3. In order to determine if all this is more than superficial impression, and in order to find out just what the college graduate sees when he looks at the foundry industry, we decided to ask him.

4. With the help of Professors A. H. White and Hawley of the University of Michigan, Dean H. B. Dirks and Professor G. W. Miller of Michigan State College, and Professors Duncombe and Linsenmeyer of our own University, we got in touch with 185 metallurgical and mechanical seniors of this year in the three institutions, believing that would be a representative sample. The three schools are, respectively, a strong state university with a national clientele, a strong land grant college with an important out-state clientele, and a private, urban school with a metropolitan clientele. In addition, Michigan is an important foundry state.

5. We asked the boys three questions.

(a) Have you ever considered a career in the foundry industry?

One hundred forty-five out of 185 seniors, or 78 per cent, had never thought even for a moment about a foundry career.

(b) Why have you, or why have you not, considered a foundry career?

The following answers are typical:

(1) "It seems that foundry work requires more practical experience than anything else, and a technically trained man would have less opportunity than one who worked his way up."

(2) "No foundry jobs were offered to us."

(3) "Our foundry course is a laboratory course, not an introduction to a career. It is accepted by most students as one more required course. It introduces a student to manual labor methods, and they are not important for him."

(4) "I never saw any literature about the foundry industry."

(5) "The industry seems still to be run by the old practical men with no regard for modern engineering methods."

(6) "I don't care for all the dust and dirt."

(7) And, over and over again, simply "I'm not interested."

(c) Do you know as much about requirements and oppor-

> tunities in the foundry industry as you know about the requirements and opportunities of the electrical, manufacturing, utility, automobile, aircraft, chemical, etc. industries?"

One hundred sixty-one out of 185 seniors, or 87 per cent, answered "No."

6. With these viewpoints it seems that perhaps the title of this address ought to be rather "The College Graduate Does *Not* Look at the Foundry Industry."

CIRCUMSTANCES AND CONDITIONS

7. Of course, all these reactions do not result primarily from the indifference of foundrymen, but result, in a large part, from unavoidable working conditions in the foundry industry.

8. In the American college, the student becomes used to a reasonably comfortable mode of life. Furniture in the dormitories and halls is good enough. Ventilation, lighting and heating are better than in most homes. Although there are very many more college students than there were twenty years ago, the college student still belongs to a selected class, an elite, and he instinctively knows it. He looks forward to a career of business or professional type, to be spent in an atmosphere of clean windows and corridors, and good furniture in a handsome office. He thinks these are the heritage of his education. They may not be essentials, but they stand out sharply when a young man is thinking about his life work.

9. The foundry, on the other hand, cannot be comfortable or elegant. In spite of great progress, a foundry is still a noisy, hot, dusty place. It will be a long time before a melting platform or a pouring floor looks like a broker's office. The boys cannot be blamed much for not rushing into the foundries. The industry does not have the slightest appeal except to a few students of metallurgy, and to still fewer students in other fields who take a certain pride in being rugged and tough, the sort who go into seafaring, oil producing, mining and the like.

10. Foundrymen who wish to enjoy the advantages of college training in their plants will need to bestir themselves because shop conditions in their industry are a severe handicap in comparison with other industries which compete for college graduates. Foundry indifference toward colleges is surely to no purpose.

THE PLACE OF THE COLLEGE MAN IN THE INDUSTRY

11. Perhaps we are taking too much for granted. After all, is there a place for the college man in the foundry craft? Before getting disturbed about college graduates in the foundries, we might well inquire if they belong there.

12. We believe there is important work for the college trained man to do in the foundry, apart from the field of metallurgy. He has accomplished marvelous results in metallurgy and furnace operation by careful and intelligent instrument work and measurement, control of temperatures and fuels, precise analysis of materials and systematic recording of data. Why should he not accomplish as much on the foundry floor? Molding, coremaking, cleaning are still to a large degree on a trial and error basis.

13. Some years ago, in the annual apprentice competition of the AMERICAN FOUNDRYMEN'S ASSOCIATION, two contestants each made perfectly acceptable castings. One had more than half the weight in risers, and the other had no risers at all. Both were employed in well known and reputable plants. This variation in practices happens not merely in molding but in practically all foundry operations. What a happy hunting ground for a resourceful, enterprising young engineer!

14. Of course, the college man must acquire work habits and skills for which college studies are no direct preparation. For one thing, he must learn to think quickly. He must make instinctive and instantaneous decisions, like the decisions made in emergencies by masters of vessels, bosses of timber crews and chiefs of power plants. Such decisions are based on experience, not on intellectual analysis. When a mold runs out or a nozzle freezes, there is no time to undertake a research to determine what to do. The boss on the floor must know what to do and must do it right away.

15. In *Time*, for March 23 of this year, there is an excellent description of men of this type: "With dog-eared note-books, pencil stubs and know how, they work out production problems that no textbook could solve. . . . They do not come ready-made; they have to grow up with the machine." It takes years of experience to produce such men, and the young college graduate does not always have years of patience.

16. I once knew a young man who began to learn the foundry business from the bottom up. He had A. B. and M. E. degrees. He learned something about molding, coremaking, cleaning castings,

pouring, oven operation and melting, the building and maintenance of furnaces. But after two years of labor he felt that he had barely made a start and he saw years of preparation still ahead of him. Just then he was asked to become assistant to the plant engineer, and to nobody's surprise, he accepted.

17. In spite of these obstacles, there is still room for the college man on the foundry floor. The very circumstances which tend to keep him out of the foundry constitute his greatest opportunity. He objects that operations are on a rule of thumb basis. They are, largely, but who can standardize operations better than he can?

WHAT TO DO ABOUT IT IN THE COLLEGES

18. Now, what is to be done to attract more college men into the industry? First of all, foundry instructors in the colleges could rather easily give to foundry technique a greater scientific color and character. We may be mistaken, and we recognize many foundry instructors who are most progressive, but perhaps too many instructors have failed to change with the times. Thirty years ago engineering inclined toward the practical. Engineers and engineering teachers scoffed at theory, and master's and doctor's degrees. But theory and science have suddenly become most important, and engineers have taken them seriously or have fallen hopelessly behind their more alert fellows. Some of the foundry instructors have not seen the light. Their courses are still emphatically shop courses. They still wink at each other when they hear the word "theory."

19. The instructors of this type must change their methods. They must get busy with research in foundry technique; in gating and risering, for instance. They must study, investigate and publish. Operations must be standardized, and they can be. Convincing proof is, for instance, the handbook on cutting metals of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS, and the design data published for all airplane manufacturers by the Civil Aeronautics Authority.

20. Military techniques have been thus standardized. In the last war, a number of New York police sergeants and a number of Texas Rangers joined an infantry regiment of which I was a member. They made fun of the *Small Arms Firing Manual* of the United States Army. Shooting was something, they said, which could not be learned from books; one learned to shoot by shooting. Before

long, however, the best shot in the battalion was a former professor of modern languages at Columbia University who had never fired a rifle in his life, but who carefully read what the manual had to say, and carried out the instructions to the letter. Foundry technique can be similarly organized.

21. Most college foundry departments now lack dignity, and the students instinctively sense that lack of dignity; they do not respect the foundry laboratory, and they will not until they see in it more of science and scientific procedure.

WHAT TO DO ABOUT IT IN THE INDUSTRY

22. If American foundrymen wish to enjoy the advantages which other industries have gained by introducing college techniques and college men, advantages which they themselves enjoy in their melting and metallurgical departments, they should begin by setting up graduate training programs for college men in their shops. These should be highly organized, not unlike the familiar apprenticeship or test courses in the larger manufacturing corporations. Foundrymen must determine the content of such training, and organize that content as formally as a college curriculum. They must organize the method of administration and select the individual who will be in charge before the first young college boy is engaged. They must determine which jobs in their plants may advantageously be held by college men, and hire just enough college boys to fill the need, allowing for inevitable turnover, and no more.

23. The program must be interesting and worth while. Forgetting the college boy is fatal. He must be groomed, watched, encouraged, talked to. Sometimes foundrymen hire a college graduate or two and promise to break them into the business. The boys may start out running stock core machines. Nine months later the boys are getting dissatisfied and we go out to investigate. They are still running the stock core machines. We protest to the boss and he answers, "They can work their way up. I did." Yes, they can, but they will not; not that slowly. Times have changed, and that particular boss, at least, had better revise his viewpoint and his methods.

24. The boys must make just enough progress to maintain their interest; and they must be paid enough to meet the competition of other jobs.

WIDE OPEN FIELD

25. In spite of its handicaps, the foundry has at least one great

vocational advantage, and that is its wide open character. One time, when I was still in the industry, a young man came and asked for a job in the foundry. He had just graduated in engineering at Dartmouth. He was well dressed; his manners were excellent; he was clearly used to the finer things of life. He did not appear rugged enough to survive in the foundry, and I tried to persuade him to enter some other department of the plant, but he refused to consider anything else. Finally I said, "But very few college men go into the foundry game." And he answered, "I know that; it's my point exactly. If I go into the foundry I will not have to compete for promotion and opportunity with half a hundred other college graduates who have had as good training as I have had. I should get on faster there." That will be true for years to come, and it might interest others of our best young men.

26. The foundry, with its rapid strides in engineering applications—mechanical, metallurgical, electrical, management—to meet competition from similar developments in other engineering and industrial fields, provides the engineering graduate with opportunities little realized by engineering students, their instructors, those in charge of engineering departments and the majority of executives in the foundry industry.

DISCUSSION

Presiding: F. G. SEFING, International Nickel Co., New York, N. Y.

J. T. MACKENZIE, JR.[1]: I agree with the speaker that probably the fault lies in the presentation of the subject by the colleges to the students and in the relative indifference of the foundry industry as a whole. I believe the industry has a real opportunity now, with the recent tremendous growth in the use of castings in the modern steel game and the aircraft field, to present itself not only to students but to the public at large, by showing what an important part it is now playing and what great progress has been made toward increasing the scope of the foundry industry as a whole.

The first point is the presentation of material to the colleges or to the college boys by the colleges, which has been covered fairly well. I believe a foundry course should be not only a practice course but that we should try to get the colleges to lay a little more stress on related courses in the scientific aspects of the foundry which are many and varied. They are not stressed now because of the hitherto relative unimportance of the foundry in the tremendous presentation that all the colleges try to give, but I am sure it merits more attention now that it has been given

[1] Carnegie-Illinois Steel Corp., Pittsburgh, Pa.

in the past. With a sufficient education of both the public and the faculties of the colleges, it might be possible to get engineering books, which now give one paragraph and sometimes two to the topic, to give it more emphasis.

The second point is more in the nature of a recommendation. The representatives of various corporations, regardless of type, go around to the colleges not one but five and six months before graduation, or sometimes during the whole school year, not necessarily to recruit, but to say, "We are coming here next year. We have certain jobs open. We are looking for men, and if any of you are interested, we would like you to think about it." The good engineers and the good metallurgists have offers for jobs in January and February before graduation. Sometimes they accept and then regret their acceptance, because the first job may not be the one they like best, but for the lack of the opportunity to choose, they will take the one that offers the most money. If they knew that a representative of the foundry industry would come in a month or so to present certain opportunities, they would wait, whereas if the foundry representative waits until May or June, all the good boys may already have been taken.

R. W. BISHOP[2]: I think that Dean Freund has obtained a good cross section of the college undergraduates' opinion of the foundry industry. However, I believe that many students of metallurgical courses who have become even slightly familiar with foundry operations have a definite interest in the foundry industry. There were at least four of the fifteen metallurgical engineering students in our 1941 graduating class who were interested in the foundry business. All of these men had had previous experience in foundry work. Consequently they were well aware of the unfavorable conditions of dirt and heat that exist in a foundry. Despite this they were sufficiently interested to discuss the possibilities of starting a foundry or getting a start in the foundry business.

CHAIRMAN SEFING: Did all four of them get into the foundry business?

MR. BISHOP: No. Two are directly connected with production and research on castings. The other two are engaged in other phases of metallurgical work.

J. F. OESTERLE[3]: It has been said that most of the men in the foundry are the sons of the owners. I think the reason this is true is more or less because these boys have been practically brought up in the foundry. Vacation time contributed many opportunities for learning to know the foundry.

This idea of breaking boys in gradually should suggest an opportunity for the average foundry. They could take in half a dozen boys at the end of their junior year in school and find something for them to do during the summer. There are many jobs that they could do, and there could be no end of observation of how they did them. The likely boys could be pointed toward greater opportunities, and there are many boys who

[2] Union Carbide and Carbon Research Laboratories, Niagara Falls, N. Y.
[3] University of Wisconsin, Madison, Wis.

would like to hear at the end of such a summer, "When you graduate, we have job for you, if you want it."

MEMBER: Along that line, at our company, we give all our employees' sons jobs for the summer. During the depression, we could only take the boys who were in college, but ordinarily we take the boys who are graduating from high school.

Boys working their way through college are allowed to work 4 hours a week during the school term at our plant, and we have quite a few doing it. We usually keep 4 or 5 of them in the laboratory and testing department, and the shop usually keeps 4 or 5 such jobs, so that we nearly always have 8 or 10 young men going to the local colleges, and, at the same time, getting a real apprenticeship in our shop and learning our way of doing things. By the time they graduate, they feel that they belong to the organization. As a matter of fact, most of them do go right to work.

CHAIRMAN SEFING: The young men who become associated with your organization in that way sense the interest that everybody has in them as individuals, and that is one of the reasons why they are anxious to get into your shop.

Another important point is that of a college foundry making castings. No matter how much effort is put into it, the student learns very little about making good castings. By deliberately making poor castings, and having them as examples of why the sand has to be rammed up uniformly, why the moisture content has to be at this level, why the gates have to be so large and be at this particular spot, etc., he learns the rules which govern foundry practice. There is a lot of opportunity in that direction.

PROF. OESTERLE: I would like to emphasize what Dean Freund has said. I understood from his paper that there is a lack of cooperation between industry and technical schools. Four years ago a professor of mechanical engineering, who had supervision over the foundry department, told me they were dispensing with their foundry in favor of a hydraulic laboratory because there was no demand on the part of the foundries in their district for graduates or for those who had had foundry courses, whereas there was a demand for hydraulic laboratory graduates.

In the same district there were many steel foundries catering particularly to the railroad industries. The local A.F.A. chapter strove hard and succeeded in getting a night course in one of the local trade schools for apprentices or for men to learn something about the foundry industry. In other words, a course in college was apparently not a practical one. A lot can be done by the industry in the schools in trying to find out the needs and satisfying them.

Engineering Graduates in the Foundry†

By S. D. Moxley*, Birmingham, Ala.

Abstract

The purpose of this paper is to discuss the place of the engineering graduate in the foundry industry. The author tells of the growth and progress of the foundry industry and its need for increasing numbers of young men with technical knowledge. He describes the training system used by his company and its advantages, stressing the importance of making provision in training programs of this type for young men who are not college graduates.

1. Just a few years ago, the foundry industry was a relatively small one. The shops themselves were small, and the personnel usually consisted of several good artisans who, by long years of experience, had mastered many of the mysteries of the art. The shop was usually headed by a master craftsman, and perhaps a partner who was experienced in business. Little was known of metallurgy, and plain gray iron was the order of the day. There were many limitations in the art and these were recognized and accepted.

2. In recent years, all of this has changed. Many of the mysteries and trade secrets of the art which were then known to a few, have now been broken down and reduced to a science. The results of research work, which has been carried on continuously by thousands of workers in the industry, have been recorded, and, through our technical associations, this valuable information has been disseminated and made available to all. Great and diversified organizations are now built around the foundry, involving practically all of the sciences. The industry has become so highly mechanized that it employs all of the branches of modern engineering. So we find ourselves today, in a highly technical industry which is advancing on an ever broadening front. For this progress, we owe much to the automotive industry.

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† In the absence of the author, this paper was presented by W. T. Barr, American Cast Iron Pipe Co., Birmingham, Ala.

* Chief Engineer, American Cast Iron Pipe Co.

Note: This paper was presented before the Foundry Industry and Engineering Training Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

NEED FOR TECHNICAL MEN

3. Into this highly scientific and ever more exacting industry must flow increasing numbers of young men to serve their apprenticeships. They must equip themselves with the knowledge of the "art" and project it into the future progress of the industry.

4. The purpose of this paper is to discuss the place the engineering graduate might take in this scheme of things. In such an industry, men with a good working knowledge of the basic sciences are needed. The more technical knowledge a foundryman can put into practice, the more successful he is. Whether he gets this knowledge in college or elsewhere is immaterial, but if he is to succeed in the foundry he must have it just as surely as if he were working in the field of engineering, medicine or other professions.

5. Our colleges are undertaking to give our youth a well rounded knowledge of the sciences needed in modern industry, and it can be said that they are doing an excellent job. So it is only natural that a technical graduate, so schooled, should find a place in this highly scientific industry. Surely, he must enter as an apprentice[1], as no college has yet undertaken the task of producing a graduate who is already trained for industry. Too often he has been expected to find his place more or less unassisted, and proceed on his own steam. As a matter of fact, he may need more guidance than a trades apprentice usually requires.

6. The numerous studies and investigations in college have so broadened his range of interests, that it is likely to make it more difficult for him to find his place immediately. His shop training should follow as closely as is practical a prearranged schedule just as the work of any other apprentice is scheduled. Every effort should be made to ascertain his natural inclinations, as well as his physical and intellectual fitness for the work he is to learn. Close attention to the already established apprenticeship practices will prove invaluable in the training of engineering graduates. Too often this has been overlooked.

7. It has been said that the foundry industry needs engineering graduates, and that the industry should try to sell itself to them. Rather, we need to explain to these boys and the colleges whence they come, the scope of our work, the progress it has made and the opportunity which it offers to those who are willing to work and to continue their studies after leaving college. Once this

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[1] In this paper the terms apprentice and apprenticeship are used in their broader meaning.

is known, there will be little trouble in finding boys of the highest caliber who are willing and anxious to meet all of the strenuous requirements of the foundry. In our experience, we have not found many of these boys who are looking for white collar jobs. Most of them prefer to work in the operating department, rather than in the office. They are prepared to do manual labor on any of the various shifts to which they might be assigned during their training.

APPRENTICESHIP PROGRAM FOR TECHNICAL GRADUATES

8. The American Cast Iron Pipe Company operates an apprenticeship program designed for technical graduates and those young men who are more advanced in education, training and age.

Selection of Applicants

9. This system is directed by a committee composed of five department heads. An applicant is interviewed by each member of this committee before being employed. In making the selection, the committee usually gives equal weight to scholastic record, student activities, and personality, attempting to select young men who have the potential qualifications for supervisory work. This group comprises technical graduates in the various fields of engineering and chemistry, and young men in the plant who have shown exceptional qualities of leadership, regardless of their formal education.

Training Schedule

10. The schedule provides for short periods of service in the various departments of the company's business such as production, metallurgical, research, engineering, personnel, sales, and maintenance. The training period usually requires from 2 to 3 years for completion. The committee holds formal meetings to direct the schedule followed by each apprentice and to discuss the progress he makes in each department.

Advantages of Program

11. This system offers those in authority opportunity to study the progress of each apprentice. It enables them to ascertain if the apprentice is suitable for the field of work in which we are engaged, and if so, for which particular phase of the company's

business he is best suited. In other words, it is the practice of vocational guidance by trial and error.

12. This system offers the further advantage that, before entering into one particular phase of the business and specializing in it, the student has had an opportunity to gain a good working knowledge of all phases of the business. Such experience gives him a better perspective of all departments of the business, and this results in higher efficiency and better cooperation later on.

13. This apprentice training program has been in operation for about 8 years. We can see many beneficial results from the work that has been done. This system is used because it is felt that it suits the needs of our plant, but we would have no hesitancy in changing to another method which better suited our needs, should one come to our attention.

14. It will be noted that our apprenticeship program provides for young men who are not college graduates, but who have shown exceptional qualities in their work. We think this important, as provision should always be made for the boy who could not get a formal technical education, but who is willing to make the necessary sacrifices on his own to get the technical knowledge required. From such boys our training program has developed some of our most capable young men.

DISCUSSION

Presiding: F. G. SEFING, International Nickel Co., New York, N. Y.

CHAIRMAN SEFING: The American Cast Iron Pipe Company has been one of the leading companies in selling itself to young engineering students. One point brought out by the paper reminded me of the time I decided to turn my interests to the foundry business. For the first few years after I came out of school, having taken a metallurgical course, I was working on steel problems, and I found the competition so terribly keen and myself so wholly inadequate to compete with that situation, that I decided to go into another field of metallurgy where there were not so many metallurgists. The opportunities are here, and the paper presented by Mr. Barr certainly shows what some of those opportunities are.

C. J. FREUND[1]: Are the college boys taking this foundry apprenticeship course at the American Cast Iron Pipe Company of the same social standing as those who are taken from the colleges to work up into the engineering department proper?

MR. BARR: So far as I know, there has been no young man taken into our company to work directly into the engineering department without first going through this training period. There have been one or two

[1] Dean of Engineering, University of Detroit, Detroit, Mich.

whose aptitude was very definitely toward the engineering department, and their work would be a little more concentrated in that field. They go through the same training period.

MEMBER: There is a great deal of contrast between the report of the American Cast Iron Pipe Company and that of a certain company which has several large steel foundries throughout the United States. One of the personnel men of the latter company reported to me that only one out of ten of the men they get from cooperative engineering schools or technical schools who go through their training course really succeeds. I asked him whether it was the fault of the company or of the engineering school. He thought that it was apparently their own plant because they had not worked out a good method of, first, selecting the men to suit the organization, and second, carrying through or keeping in close touch with the men. He said that he felt that the young men from technical schools required still closer touch than the regular apprentices who have not even had high school education in many cases. Is there something that can be done by the A.F.A. or the schools to teach industry how to handle the boys to the boys' advantage?

MR. BARR: It would be hard to say why that particular company had trouble. We do think that no matter how important the first line supervision feels this training program of college men is, if they cannot convince their departmental heads that it is necessary, whether or not they are college men, the boys are not going to gain from that departmental head the knowledge necessary to make their stay in his department worth while.

We are fortunate in that all of our departmental heads, those who are college men and those who are not, are completely sold on this idea of training college men. We attribute a great deal of our success to that. Of course, a lot is dependent on the selection of the boys.

MEMBER: In selecting boys, do you use any aptitude or intelligence tests?

MR. BARR: I do not know of any such tests given to our young men. The system, as it is practiced at our plant, is not very definitely organized. In some cases, the cooperating schools approach the plant. In other cases, the committee will send men to the schools in our district and other districts to interview graduating classmen. If they find a man or men who, they think, offer good material for our apprentice training course, these men are brought to our plant at the company's expense. In the plant, they are interviewed by the entire committee of five men. While they are there, they have an opportunity to meet, talk to and impress, if possible, the higher supervision.

J. T. MACKENZIE[2]: There are two things of fundamental importance in this success, one being the enthusiasm of the foremen all through the plant for the plan, based on the fact that we do pick out promising young men in the plant and encourage them to take International Correspondence School courses and to go through the same course that the college men are offered. Then there is the further safeguard that we

[2] American Cast Iron Pipe Co., Birmingham, Ala.

have had for 25 years, namely, the policy of promoting our own men. If we want a superintendent, the last thing we think of is to go out and hire a superintendent. If we have not trained one of our boys to take that job, we feel very bad about it. So far we have succeeded in training the boys to take the jobs as they come along.

CHAIRMAN SEFING: I would like to emphasize one point which Mr. Barr mentioned, namely, that his company sends someone to the schools of the vicinity to interview the graduating engineers. The foundry industry has to recognize from the very beginning that it is out after engineers, and that if it wants any of these engineers, it is in competition with all other engineering industries. These other engineering industries have, for 15 years or more, gone out and made a regular survey of the schools of the district. Some of the larger companies take the best of the graduate engineers throughout the country. If we are going to get some of these first-rate engineers in our industry, we have to set up a mechanism by which we can contact the graduating engineers and sell our industry to them.

There is another point I would like to make in the form of a question, "What proportion of the young men going into the foundry business find that they just do not like the smoke, dirt, sand, etc.?" When I was still teaching, some of the boys would mention that they were going to specialize in metallurgy. One of the things that I insisted on then was that they would get a job during the summer working on a furnace at one of the plants near their home. If a man can go through a whole summer, being uncomfortable around a furnace and come out still wanting to be a metallurgist, he will probably succeed. There was quite a high proportion of these men who came back and took up something altogether away from engineering. It was a good thing that they found it out for themselves as early as they did.

MR. BARR: Before coming to this meeting, we went over a blueprint which shows our entire plan on which we have listed the names of the young men who have been in a period of training and the departmental headings under which those men might work. Of the men listed, 60 per cent are still in the foundry. Some of the original group have shown much greater aptitude in engineering, sales, etc., and have progressed out of the foundry into the job for which they are better suited, but 60 per cent are still left in the foundry.

R. E. WENDT[3]: When companies sent representatives to interview the engineering students, I inquired how many foundries asked to have college graduates. I was informed that the foundries do not come around to ask for any college graduates. There does not seem to be any demand or request for college graduates from the foundry industry.

CHAIRMAN SEFING: Part of the activity of the A.F.A. Committee on Cooperation with Engineering Schools shall be to work in the direction of exciting the foundries to sell their wares to the engineering students. We think we are doing a pretty good job in selling the importance of the foundry industry to the engineering schools. We are not going to let up

[3] Purdue University, Lafayette, Indiana.

on that activity, but we are certainly going to branch out into exciting a little more activity on the part of the industry itself.

MR. MOXLEY (*author's closure*): I have read with keen interest the discussion following the presentation of my paper. I believe Mr. Barr and Dr. MacKenzie have adequately answered the questions brought up, but at the risk of repetition, I should like to emphasize several points.

Apparently, there is some question as to whether a college boy is willing to meet the strenuous work requirements of the foundry. In selecting college boys for our company, we do not have a specific job or department in mind. Our chief concern is whether or not the applicant is suited for our type of industry, and the work he does during the training period in the various departments indicates and nearly always determines the department or type of work to which he is best suited. We are never interested in a boy who is not willing to begin at hard work and on odd shifts, even though we may think his final destination will be the Engineering Department or so-called "white collar work."

In selecting the graduates, we believe that the judgment of five men, each coming from a different background in our business, is more practical for our purpose than aptitude or other such tests which have come to our attention.

It may surprise some to know that of more than 250 boys interviewed by the writer in a period of five years, less than half a dozen seemed unwilling to start out at hard work and at odd hours. Actually, they enthusiastically accept the chance to get into the hard work of our training program. We find the boy not trying to dodge hard work but rather looking for it, if along with if he can see a program ahead that will lead to advancement based on merit.